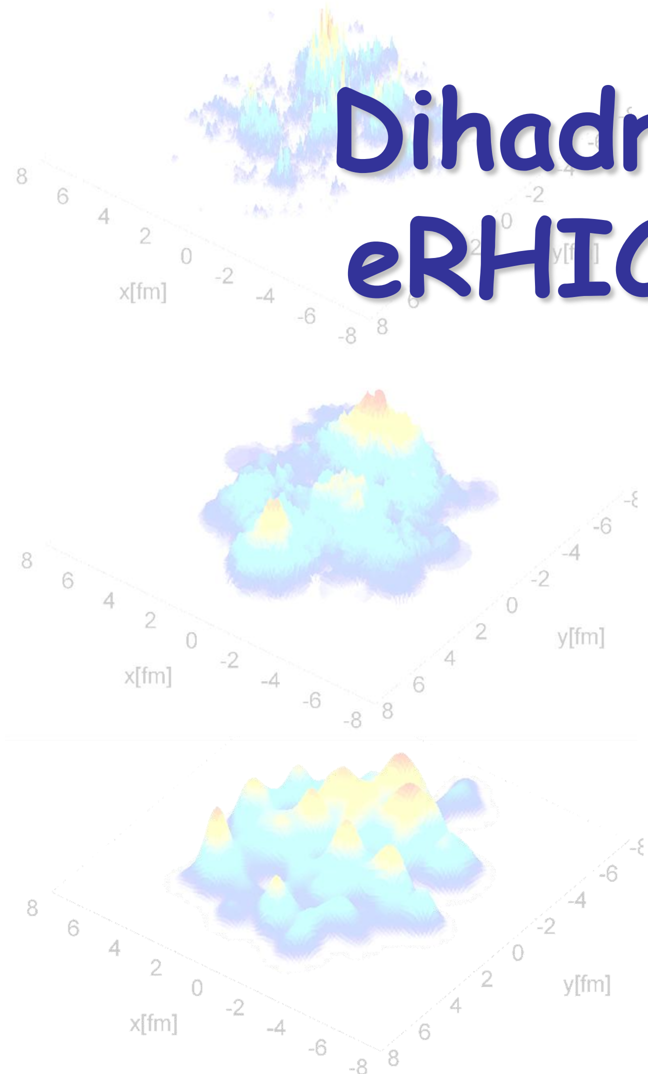
Dihadron correlations at eRHIC and Monte Carlo development



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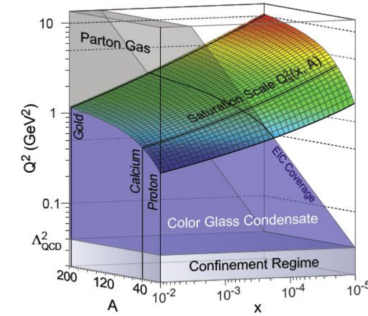
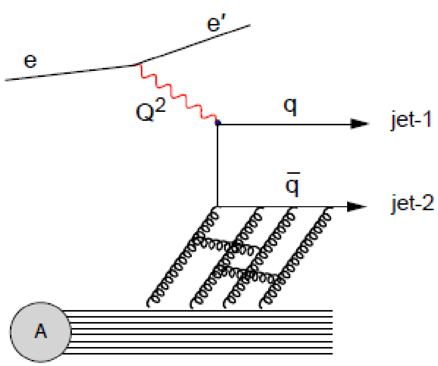
Outline

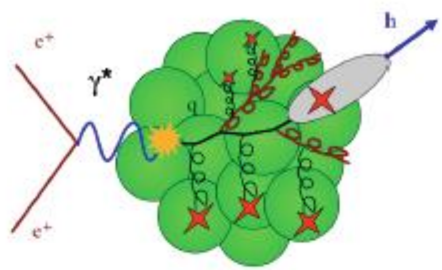
- Motivation
- RHIC forward dAu program
- Dihadron correlation at future eRHIC
  - Monte Carlo results
  - Compared with CGC prediction
  - The power of Monte Carlo
- Summary and Prospects

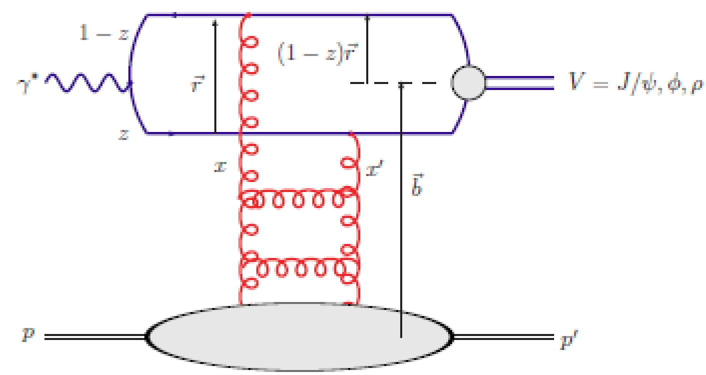
Motivation



- eA program will investigate the nuclei structure with great precision
  - Probing gluon dynamics, establish the existence of the saturation regime.
  - Study cold nuclear medium effect with parton propagation and hadronization in nuclear matter.
  - Image nuclear gluon structure.
- dihadron correlation is a key measurement in the eA program to help us explore the saturation physics.







RHIC forward dAu program

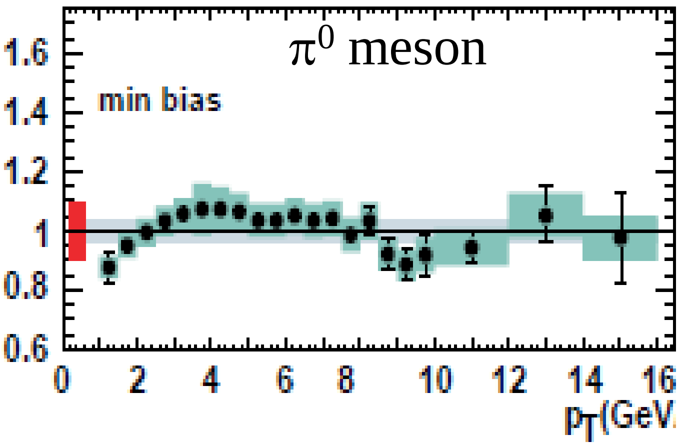
Nuclear modification factor

$$R_{dAu} \equiv \frac{1}{\langle N_{coll} \rangle} \frac{d^2N^{d+Au}/dp_T d\eta}{d^2N^{p+p}_{inel}/dp_T d\eta}$$

PHENIX $|\eta| < 0.35$

PRL 98 (2007), 172302

R_{dA}

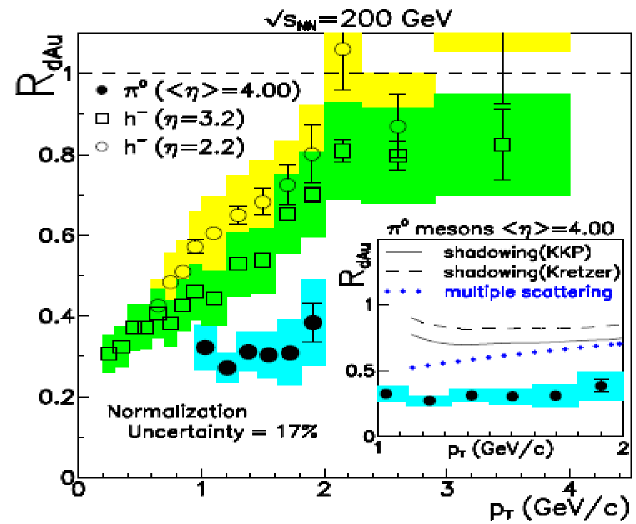


$R_{dA} \sim 1$ at mid rapidity

STAR, BRAHMS

Forward η

PRL 97 (2006), 152302



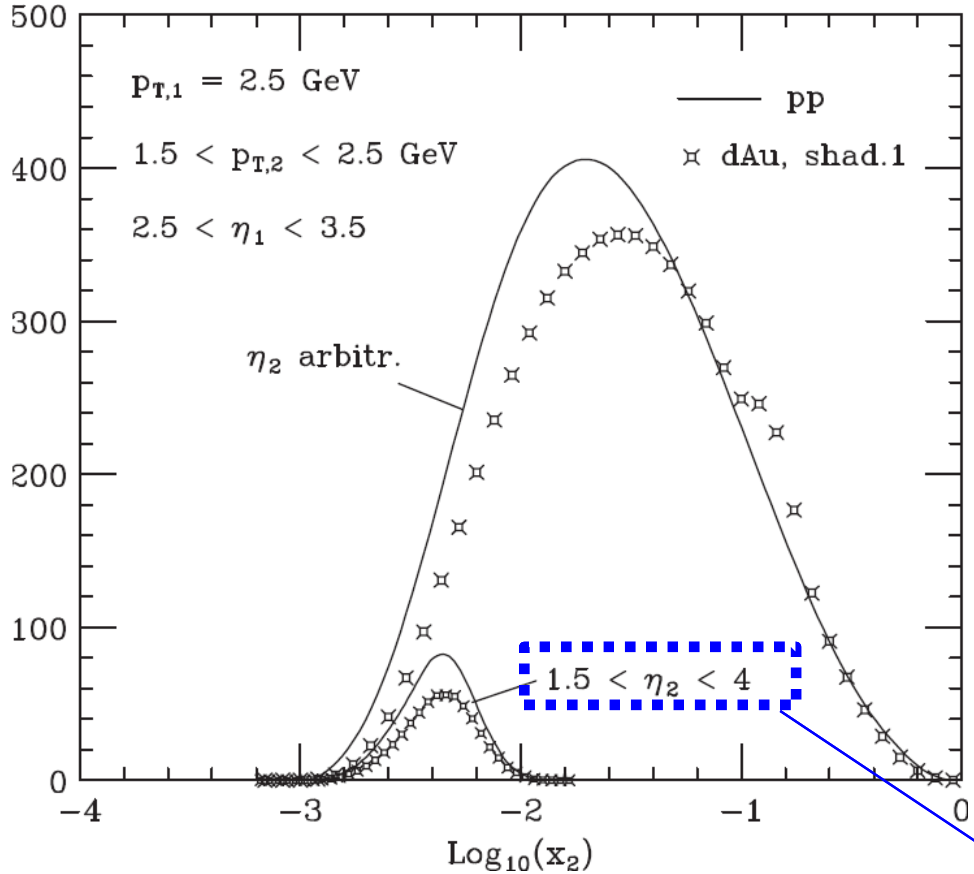
$R_{dA}<1$, Single hadron production suppressed at forward rapidity.

Cold Nuclear Matter (CNM) effect.

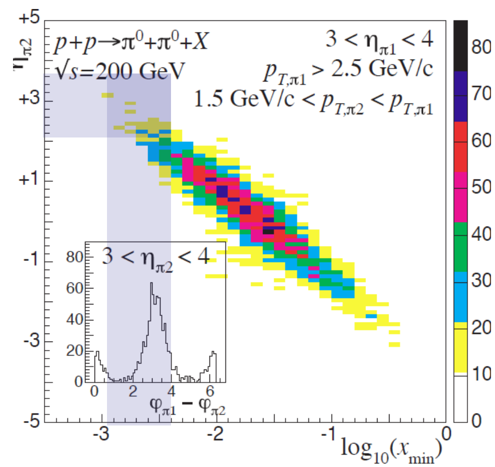
Probing small x region. $x_2 = \frac{M_T}{\sqrt{S}} e^{-y}$

Dihadron correlation at RHIC forward dAu program

Guzey, Strikman, Vogelsang, PL B603, 173



Eur.Phys.J.C43:427-435,2005



The rapidity of associate particle correlated with the x of struck gluon.

From the Pythia 2->2 process

Probably onset of saturation.

Constrain x range.

Approach to smaller mean x

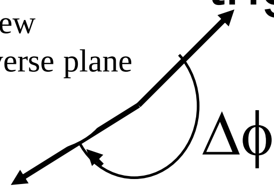
Dihadron correlation measurement

CY (Conditional Yield)

$$CY = \frac{1}{N_{trig}} \frac{dN^{assoc}}{d\Delta\varphi}$$

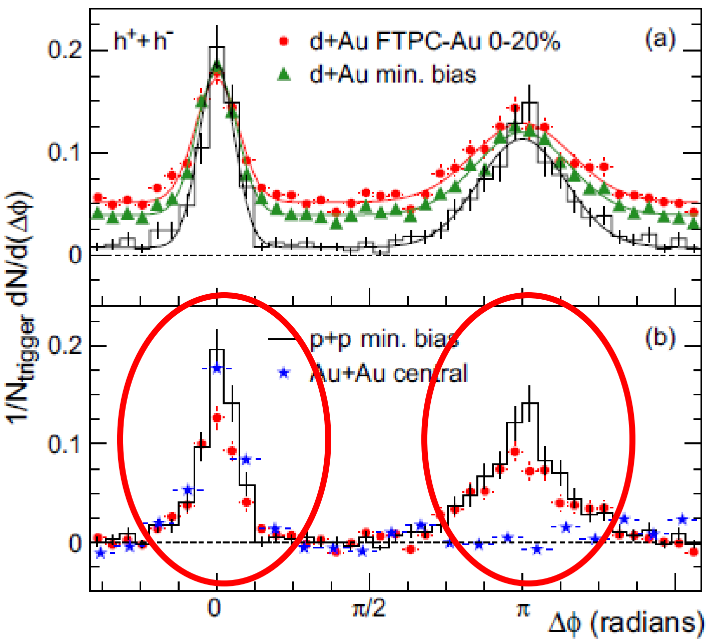
trigger (usually leading pt)

Beam view
or transverse plane



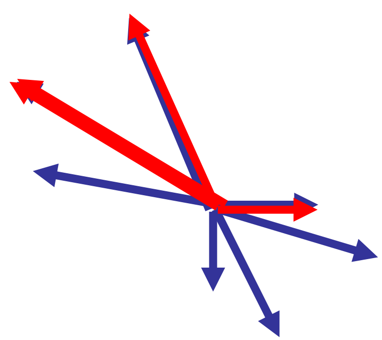
associate

Phys. Rev. Lett. 91 072304



Nearside peak: delivers jet fragmentation information

Awayside peak: medium k_T kick both from initial and final state



pp dAu dihadron correlation are similar at mid rapidity, suppression in AuAu collision is dominated by final state interaction

Dihadron correlation measurement

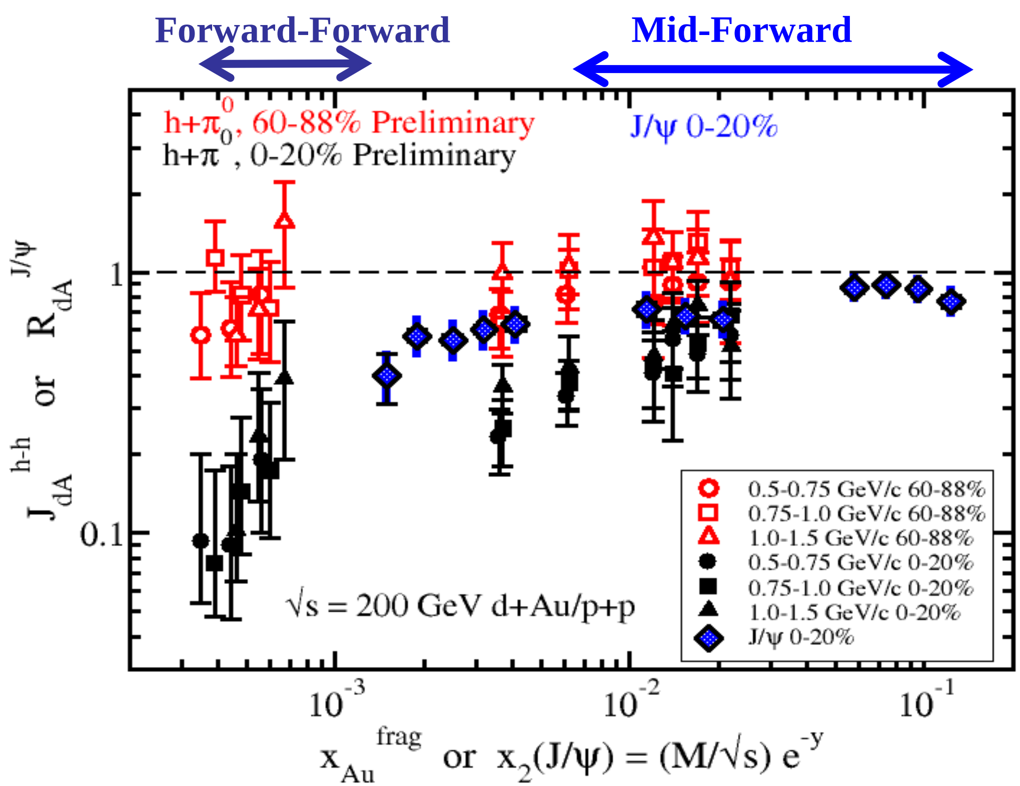
$$J_{dA} = \frac{\sigma_{dA}^{pair} / \sigma_{dA}}{\langle N_{coll} \rangle \, \sigma_{pp}^{pair} / \sigma_{pp}}$$

Dihadron pair nuclear modification factor

$$J_{dA} = R_{dA}^{trig} \times I_{dA}$$

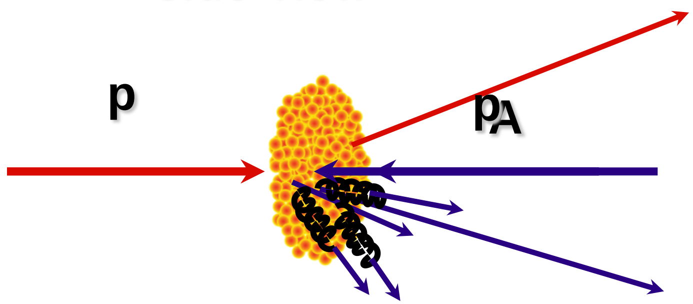
$$I_{dA} = \frac{CY_{dA}}{CY_{pp}}$$

PHENIX arXiv:1109.2133v1

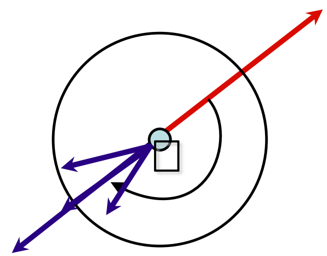


Dihadron correlation at RHIC forward dAu program

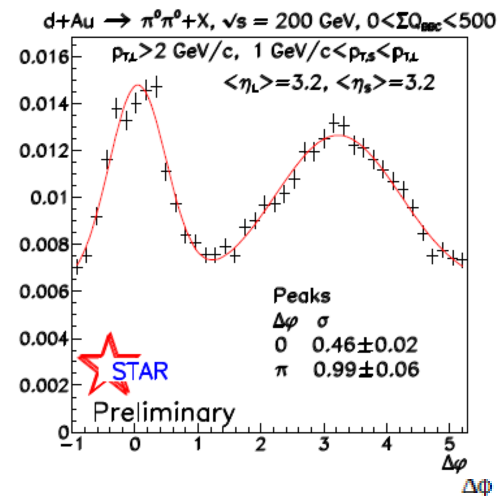
side-view



beam-view



arXiv:1008.3989v1



Low gluon density (pp):
pQCD predicts 2→2 process
⇒ back-to-back di-jet

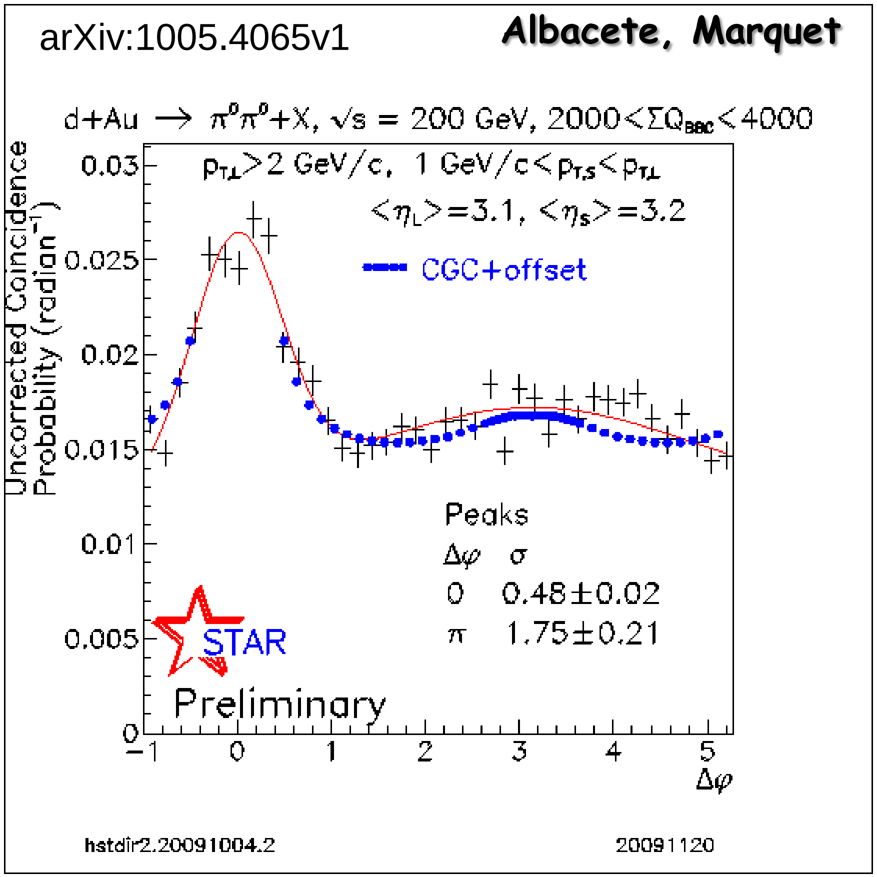
High gluon density (pA):
2 → many process
⇒ expect broadening of away-side

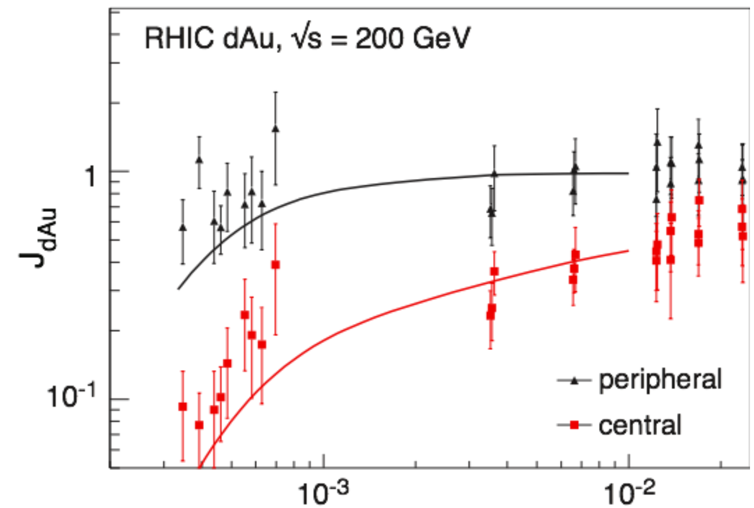
Multiple emissions de-correlate the away side peak for forward-forward di-pion correlation.

Gluon densities saturate first in the center of the nucleus.

Dihadron correlation at RHIC forward dAu program

CGC model



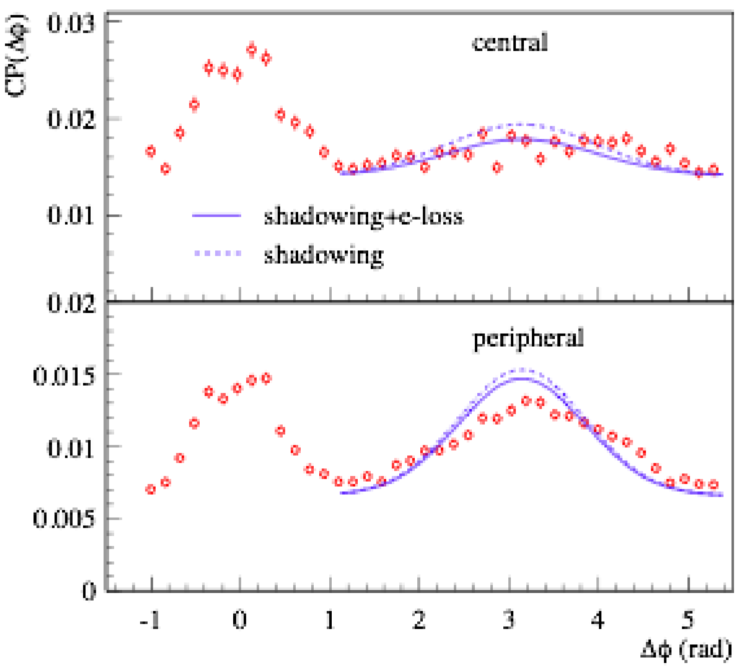


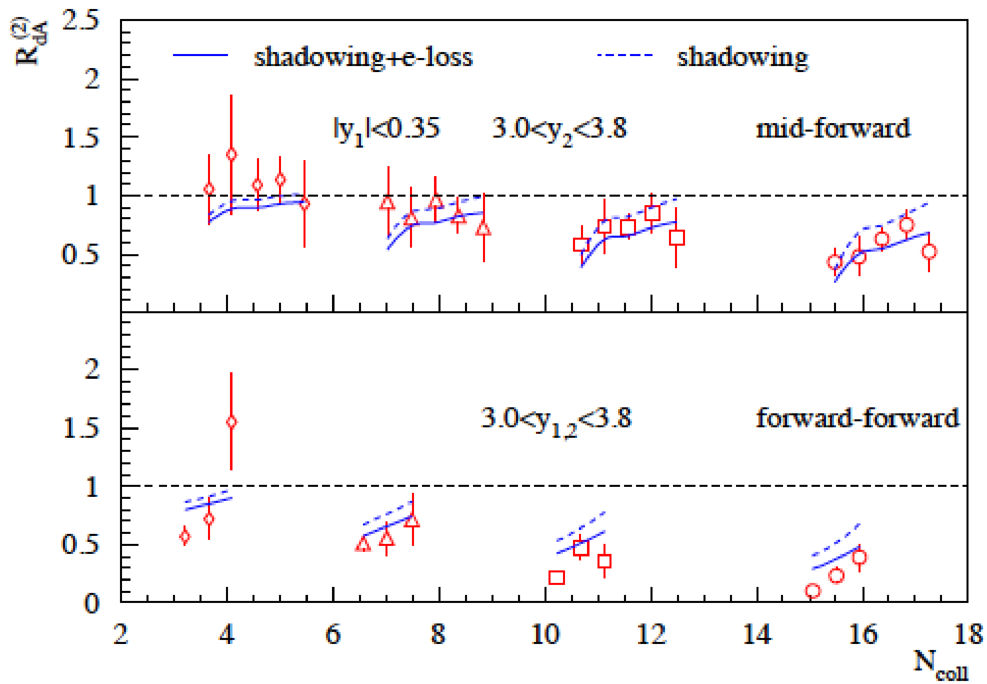
Bowen et al. 2012

Dihadron correlation at RHIC forward dAu program

Multiple parton interaction
(Non CGC formalism)

Kang,Vitev,Xing, arXiv:1112.6021v1

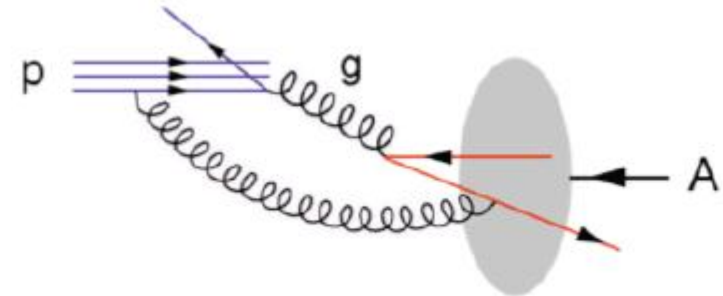




Dihadron correlation at eRHIC

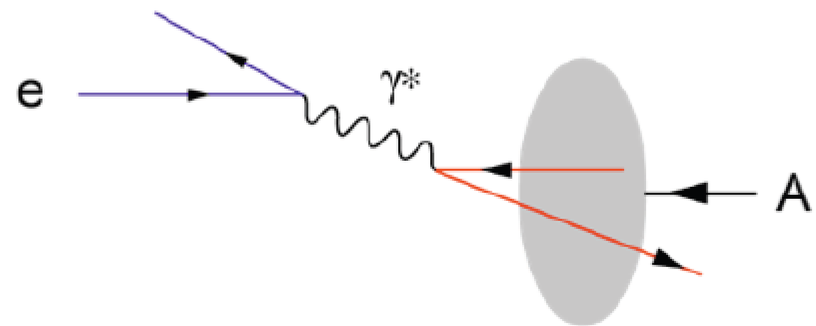
EIC:

– Extract the spatial multi-gluon correlations and study their non-linear evolution



– Control final state

- essential for understanding the transition from a deconfined into a confined state.(in AA)

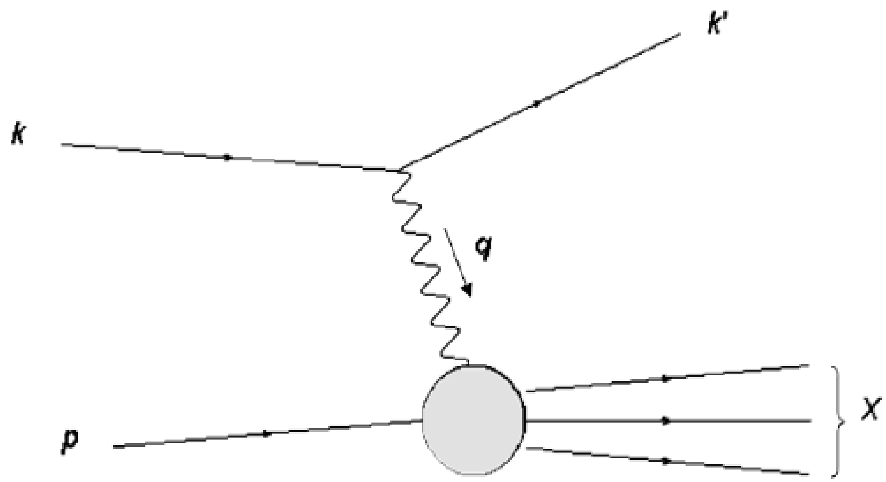


Advantage over p(d)A:

– eA experimentally much cleaner

- no “spectator” background to subtract
- Access to the exact kinematics of the DIS process (x, Q^2)

DIS kinematics



Event wise variables:

$$\begin{aligned} s &= (p+k)^2, \\ W^2 &= (p+q)^2, \\ Q^2 &= -q^2, \\ x &= \frac{Q^2}{2p\cdot q} = \frac{Q^2}{W^2+Q^2}, \\ y &= \frac{p\cdot q}{p\cdot k} = \frac{Q^2}{sx}, \\ \nu &= p\cdot q/M_p \end{aligned}$$

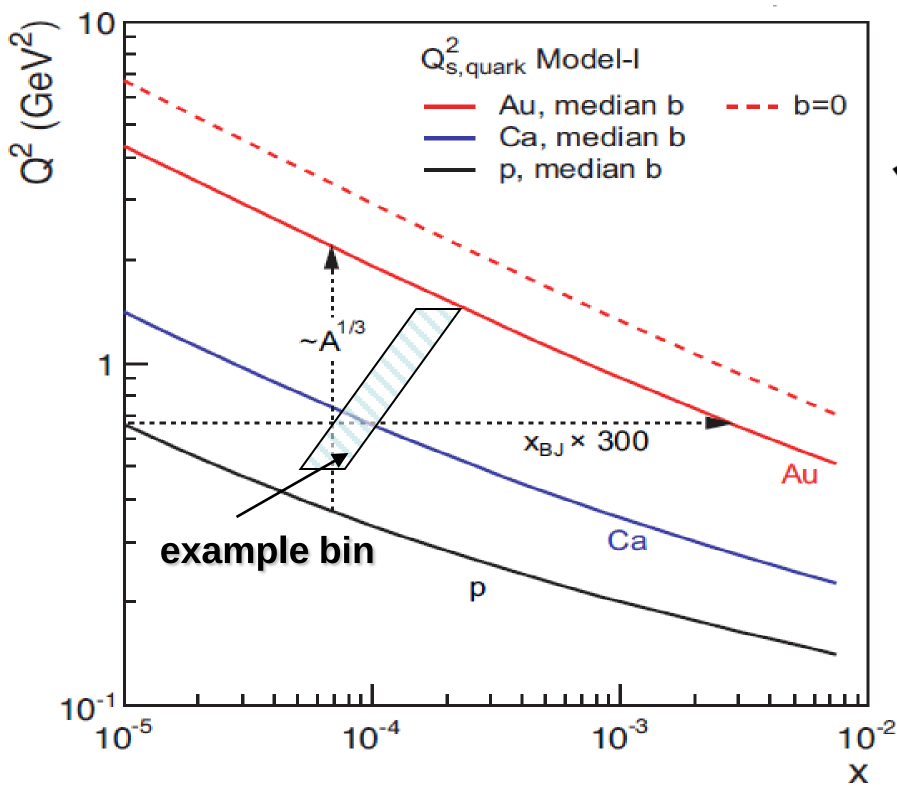
Particle wise variables:

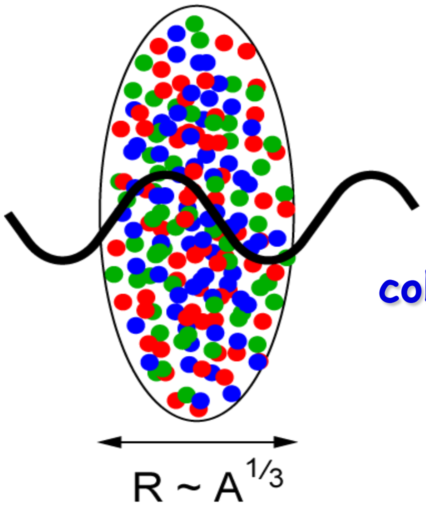
p_T is defined with respect to virtual photon

$$z_h = \frac{p_h \cdot p}{q \cdot p}$$

theoretical prediction from CGC

Pocket formula: $Q_s^2(x) \sim A^{1/3}\left(\frac{1}{x}\right)^{\lambda} \sim \left(\frac{A}{x}\right)^{1/3}$





L ~ $A^{1/3}$

Probe interacts coherently with all nucleons

Bin:0.5<Q^2<1.5GeV^2, 0.6<y<0.8

<x>=1.01x10^{-4},

<y>=0.69,

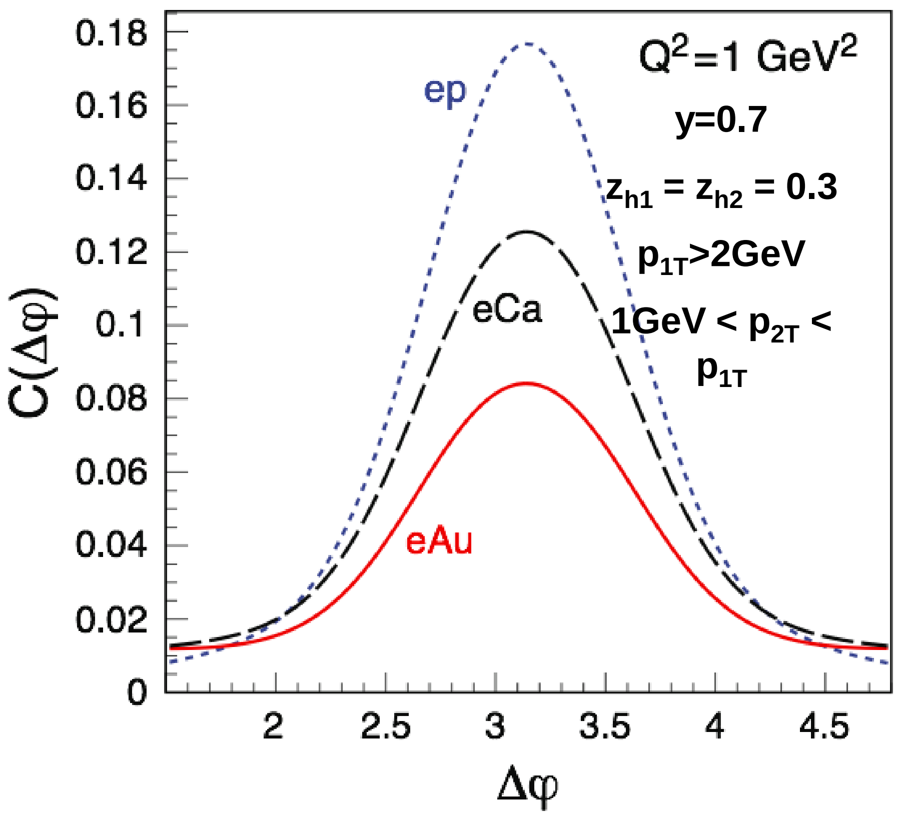
<Q^2>=0.84GeV^2,

<W^2>=8322GeV^2,

<nu>=4434GeV

theoretical prediction from CGC

Bowen, Dominguez, Yuan 2011/2012



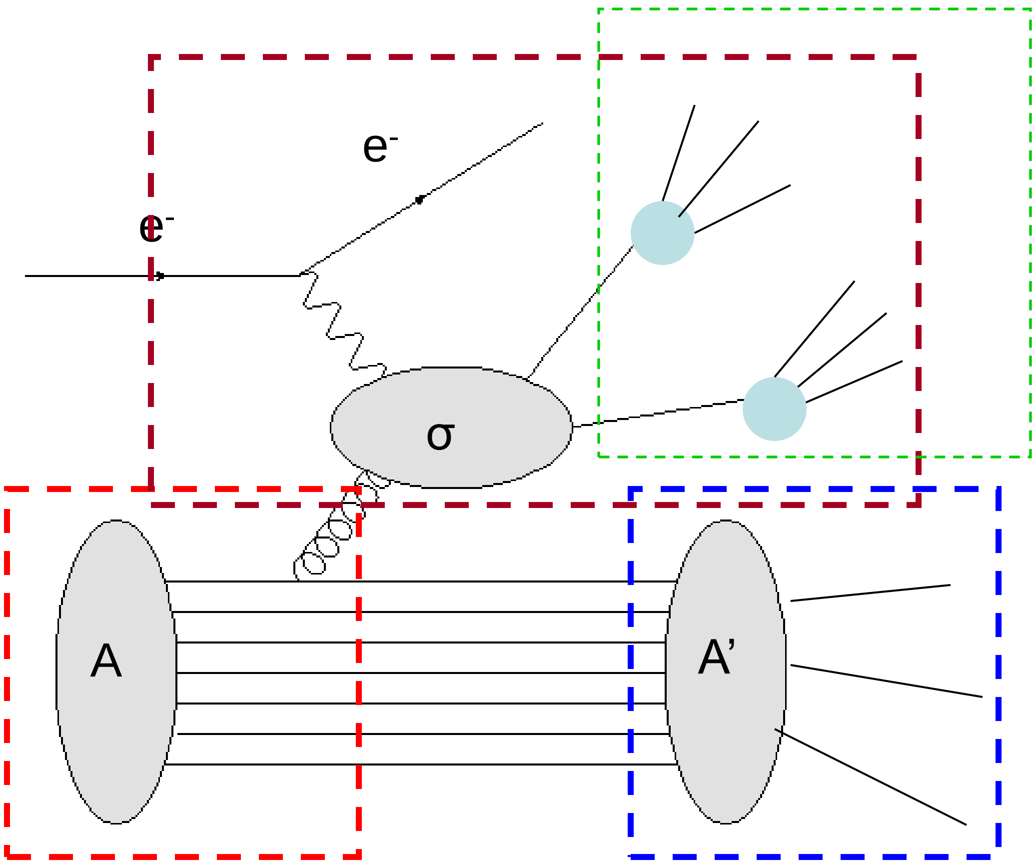
ep: $Q^2 > Q_s^2$, dilute system.

eAu: $Q^2 < Q_s^2$, dense system.

A factor ~ 2 suppression from ep to eAu at EIC energy.

Probing x range as low as 10^{-4}

Our Monte Carlo approach for the eA simulation



A hybrid model consisting of DPMJet and PYTHIA with nPDF EPS09.

Nuclear geometry by DPMJet and nPDF provided by EPS09.

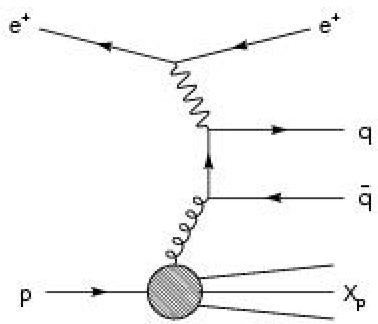
Parton level interaction and jet fragmentation completed in PYTHIA.

Nuclear evaporation (gamma dexcitation/nuclear fission/fermi break up) treated by DPMJet

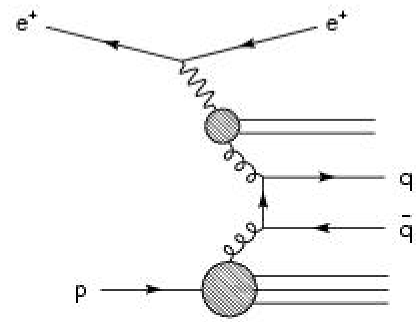
Energy loss effect from routine by Salgado&Wiedemann to simulate the nuclear fragmentation effect in cold nuclear matter (under development).

Dihadron correlation at eRHIC

PGF

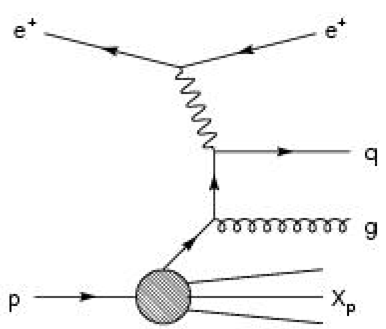


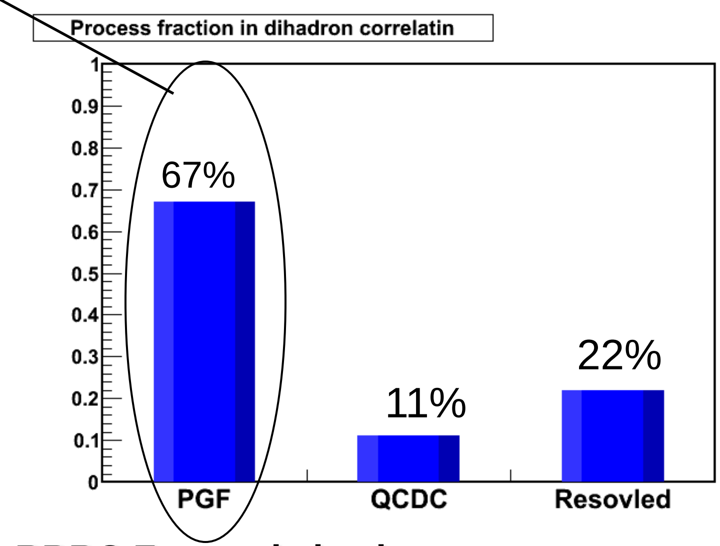
Resolved



Dominant process: Photon Gluon Fusion (PGF), sensitive to the property of strong gluon field.

QCDC



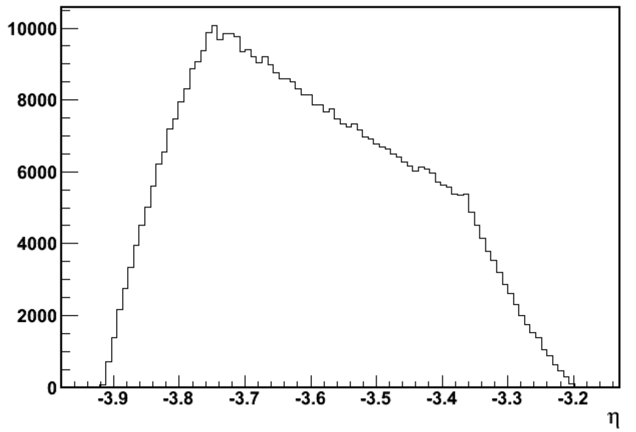


$Q^2=4GeV^2$

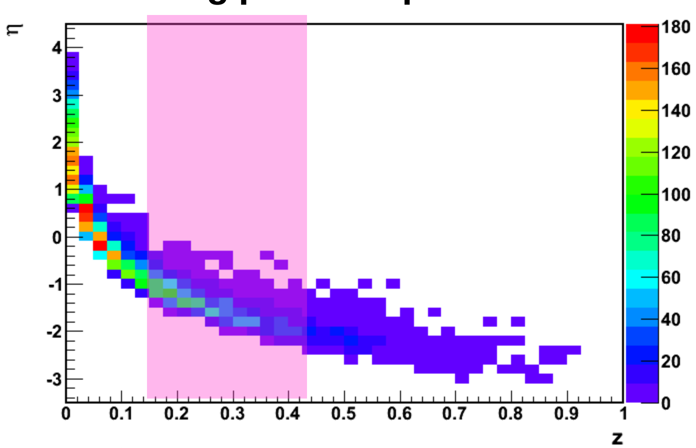
from PYTHIA simulation

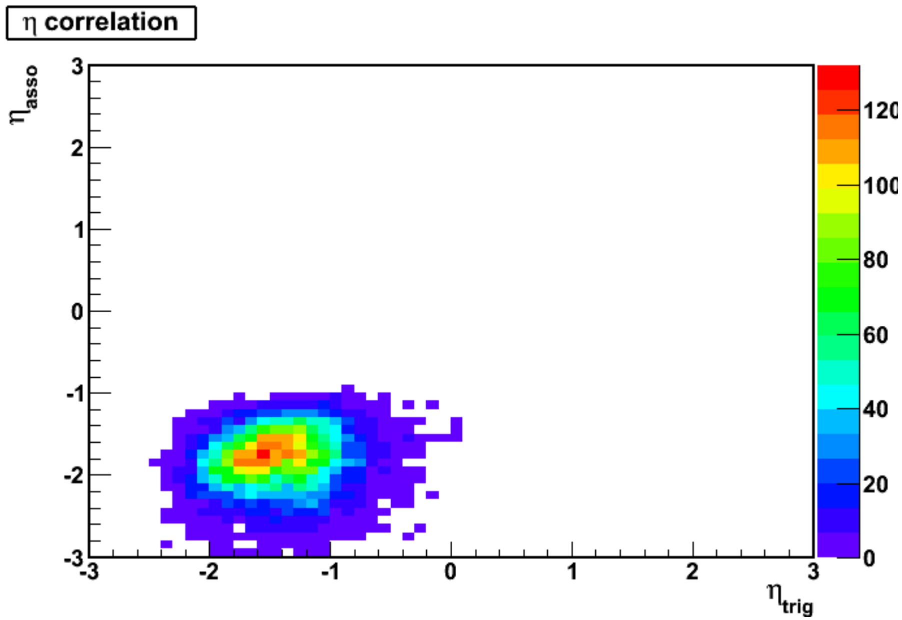
Results for Q^2=1 GeV^2

Scattered electron pseudo-rapidity



Leading particle span





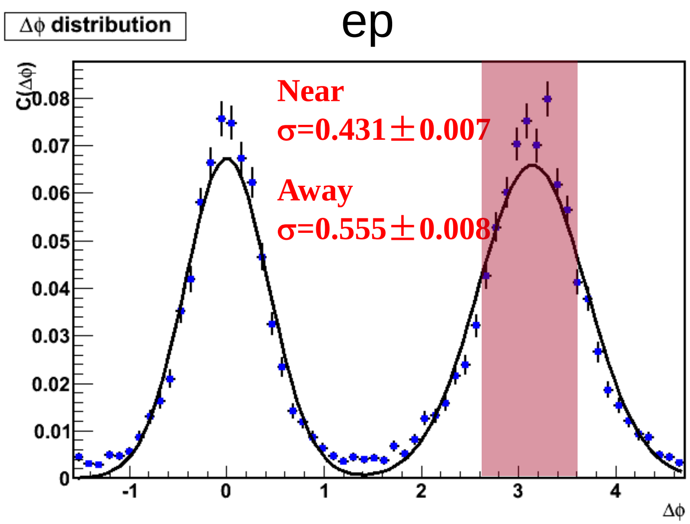
Trigger/associate particle cut:

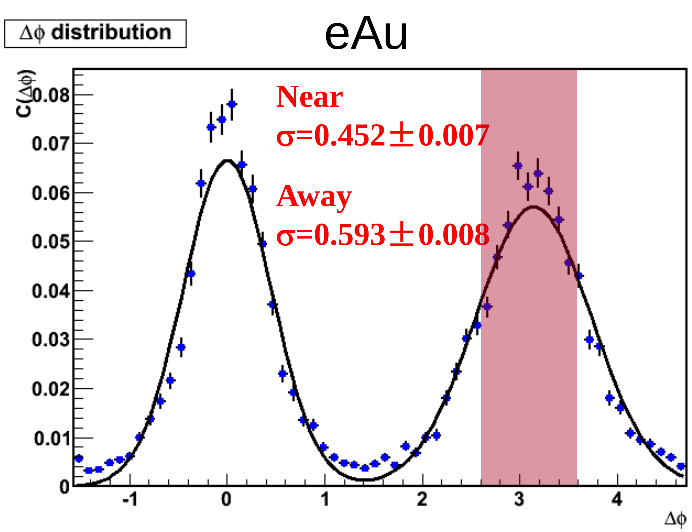
$|\eta|<4$ ($2<\theta<178$ deg),

$p_T^{Trig}>2$, $1<p_T^{Asso}<2$

$0.15<z^{Trig,Asso}<0.45$

Results for Q^2=1 GeV^2





30+100 GeV 10M events

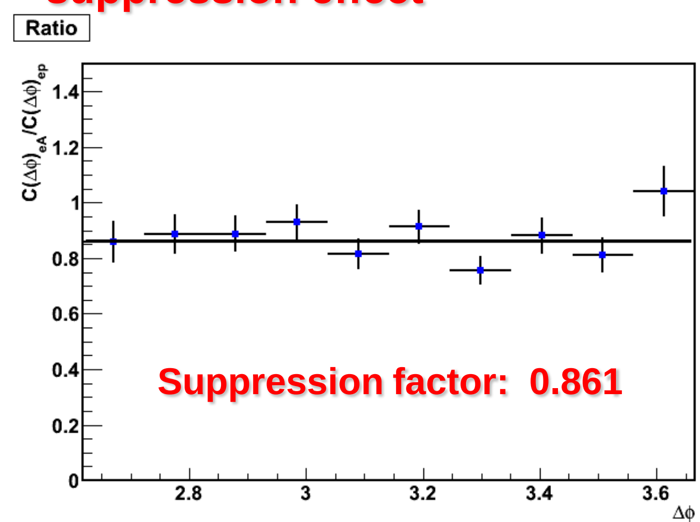
0.5<Q2<1.5, 0.6<y<0.8

|η|<4 (2<θ<178 deg),

p_T^{Trig}>2, 1<p_T^{Asso}<2

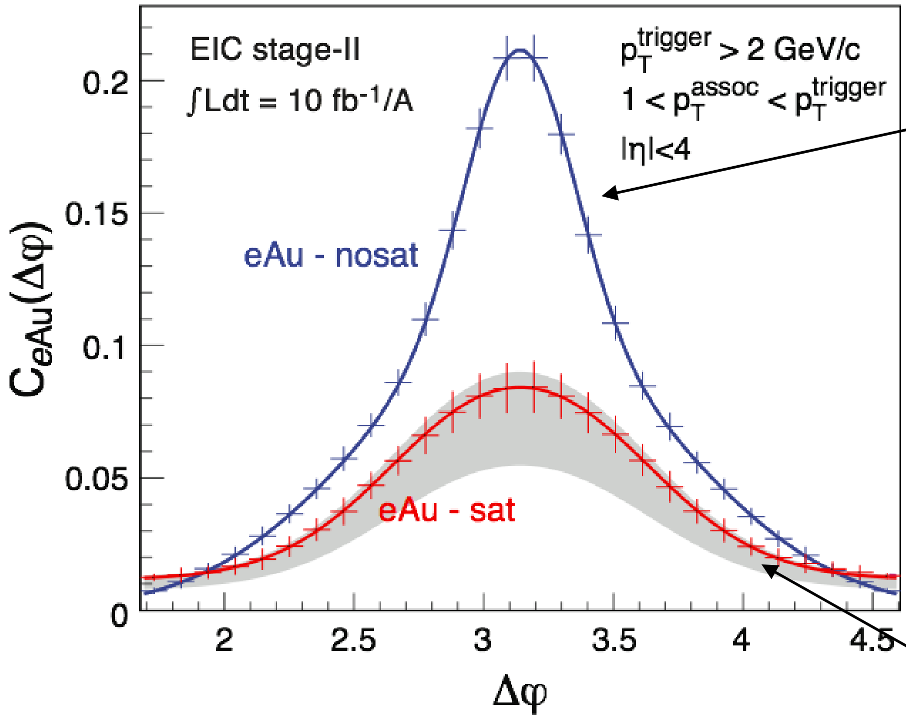
0.15<$z^{Trig,Asso}$<0.45

Nuclear PDF gives no strong suppression effect



Compare with CGC prediction

EIC white paper



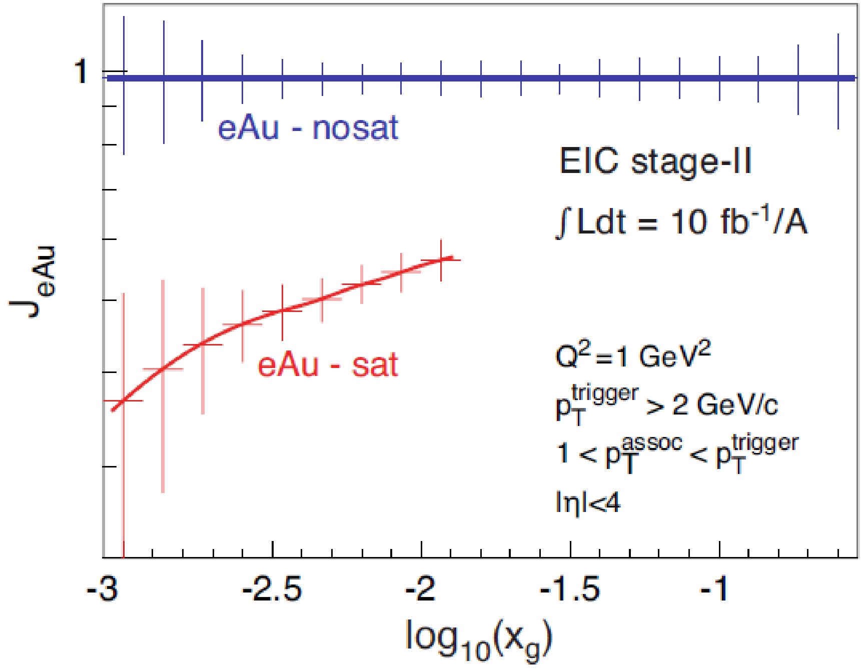
Results from our Monte Carlo, no saturation included.

A good discrimination of different models with a few months running.

Prediction from CGC calculation.

Compare with CGC prediction

Theoretical results from Bowen



Similar to JdA we can define a JeA here.

$$J_{eA} = \frac{1}{A^{1/3}} \frac{\sigma_{eA}^{pair}/\sigma_{eA}}{\sigma_{ep}^{pair}/\sigma_{ep}}$$

The absence of nuclear effect would correspond to J_{eA}=1.

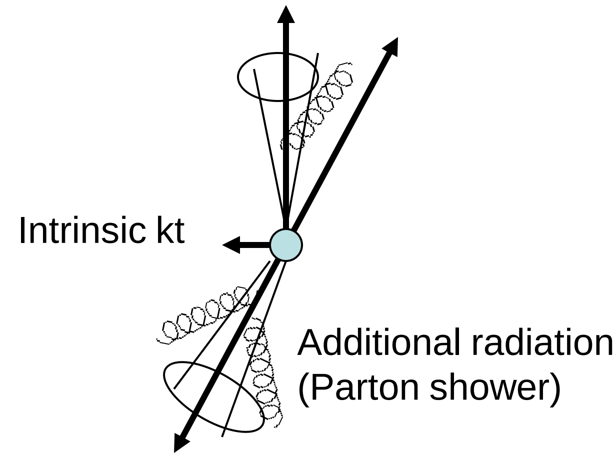
J_{eA} <1 would signify suppression of dihadron correlation.

Well controlled kinematics, pronounced signal between sat and non-sat.

The power of Monte Carlo

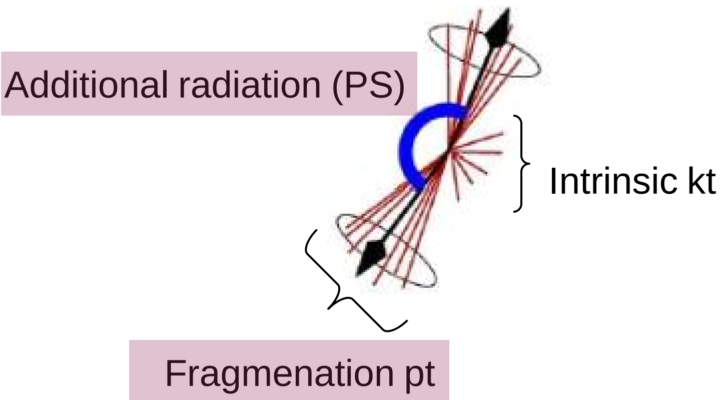
2 →2 back to back parton

Intrinsic k_T smears parton back to back correlation
Fragmentation p_T introduce p_T with respect to jet axis for hadrons.
Parton shower affects the parton p_T imbalance and the jet profile.
Medium energy loss effect



ep 30x100GeV	MC approach	Theoretical model
Intrinsic k_T	PARP(91)=0.4	$0.4<Q_s^2<0.6$ GeV^2
Fragmentation p_T	PARJ(21)=0.4	$<p_T^2>=0.2$ GeV^2
Parton shower	IS/FS	Not available

The power of Monte Carlo



With only intrinsic kt, no fragmentation pt, no Parton Shower

MC side	Theory side
Intrinsic k_T = 0.4 GeV	**$0.4<Qs^2<0.6$ GeV^2**

ep 30x100GeV

MC cuts:

$3.5<Q^2<4.5$

$0.65<y<0.75$

pt trig>2GeV

$1<p_T$ asso$<p_T$ trig

$0.25<z1,z2<0.35$

Theoretical input:

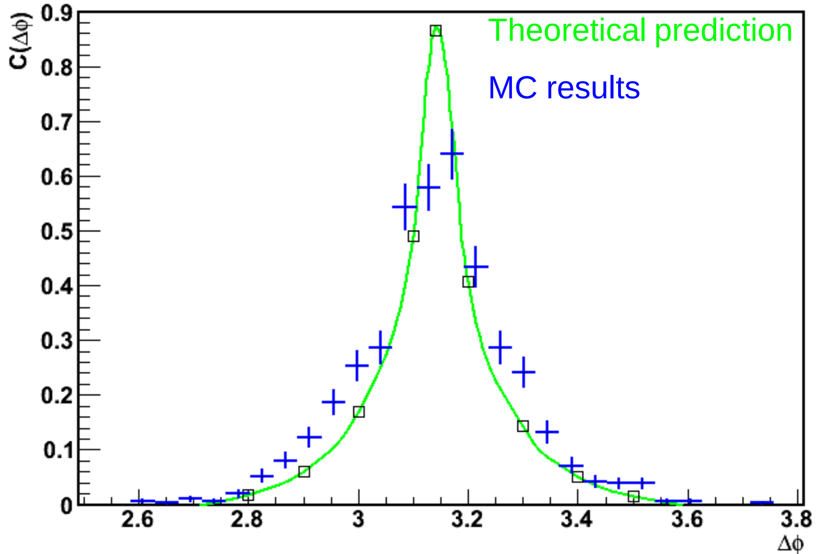
$Q^2=4$

$y=0.7$

p_T trig>2GeV

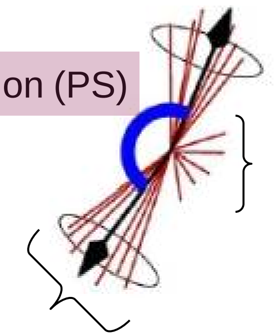
$1<p_T$ asso$<p_T$ trig

$z1=z2=0.3$



Theoretical curves from B.W.Xiao

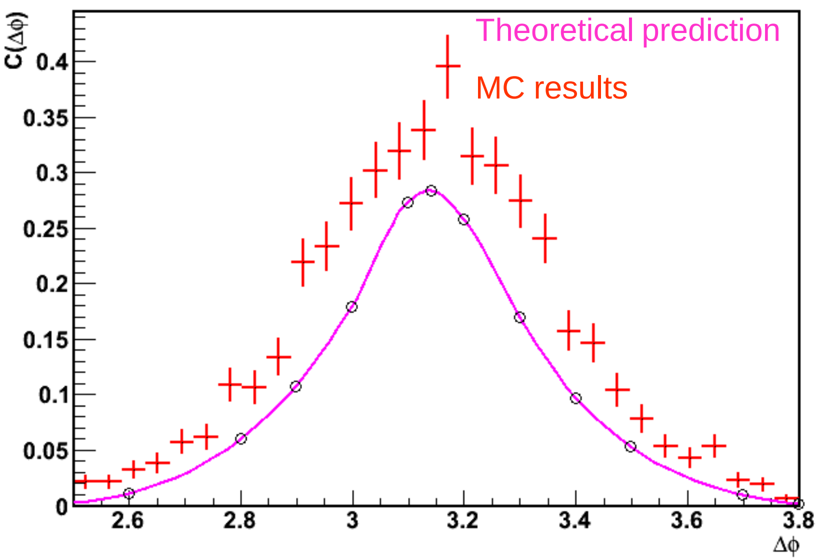
The power of Monte Carlo



Intrinsic kt + fragmentation pt, no Parton Shower

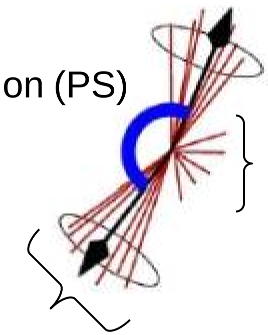
MC side	Theory side
Intrinsic k_T = 0.4 GeV **Frag p_T = 0.4 GeV**	**$0.4<Qs^2<0.6$ GeV^2** **$<p_T^2>$ = 0.2 GeV^2**

Seeing the fact that we have different treatment to PDF and fragmentation process, we have come to an agreement in ep for these two approaches.



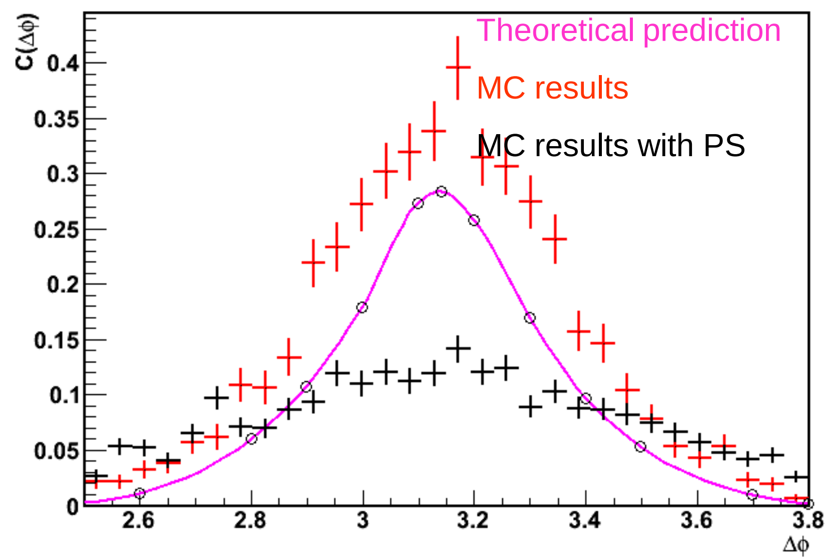
Theoretical curves from B.W.Xiao

The power of Monte Carlo



Intrinsic kt + fragmentation pt, with Parton Shower on

MC side	Theory side
Intrinsic k_T = 0.4 GeV **Frag p_T = 0.4 GeV** **Parton shower on**	**$0.4<Qs^2<0.6\ GeV^2$** **$<p_T^2> = 0.2\ GeV^2$**



Theoretical curves from B.W.Xiao

As parton shower in MC can be used as a good way to compensate the theory results.
Stretch the theoretical curve of eAu based on the PS effect on ep.

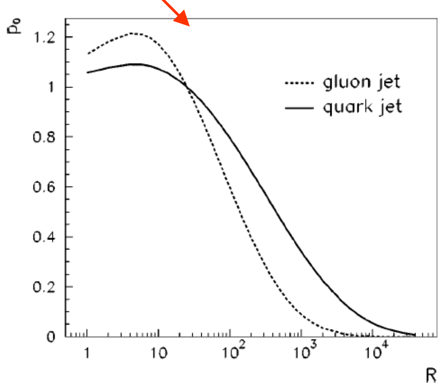
Energy loss effect under development

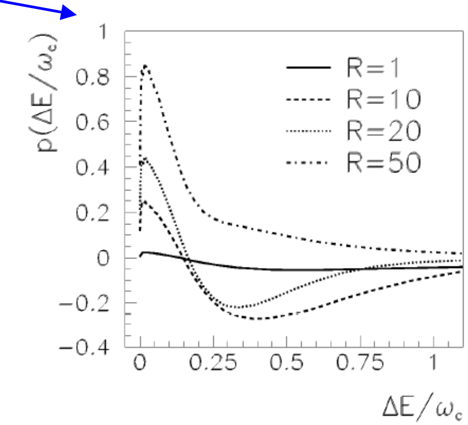
Possible to include some final energy loss effect.
According to PyQM developed by Raphael.
The probability for a parton to loose energy ΔE is given by

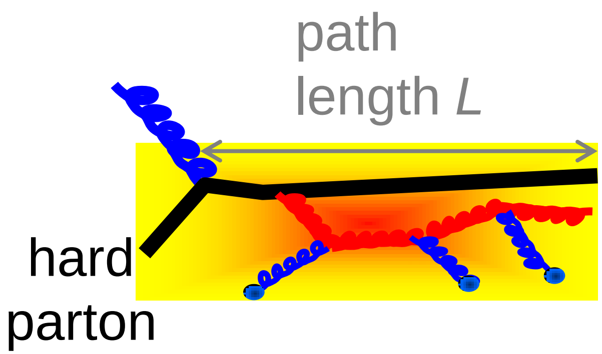
$$P(\Delta E) = \sum_{n=0}^{\infty} \frac{1}{n!} \left[\prod_{i=1}^{n} \int d\omega_i \frac{dI(\omega_i)}{d\omega} \right] \times \left(\Delta E - \sum_{i=1}^{n} \omega_i \right) \exp\left[- \int d\omega \frac{dI}{d\omega} \right]$$

Salgado & Wiedemann PRD 68, 014008 (2003)

$$= p_0 \, \delta(\Delta E) + p(\Delta E)$$







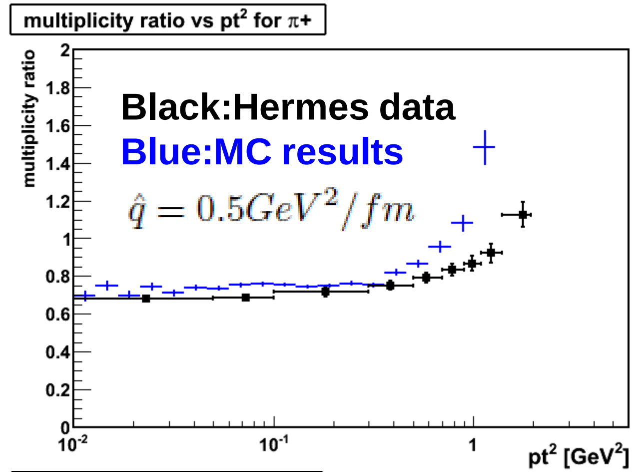
This radiation spectrum usually depends on the length of medium L, and the transport coefficient

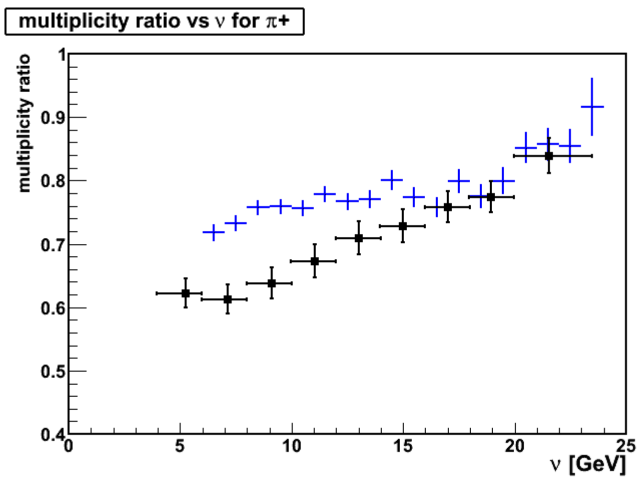
$$\hat{q} = \langle k_t^2 \rangle_{\text{medium}} / \lambda$$

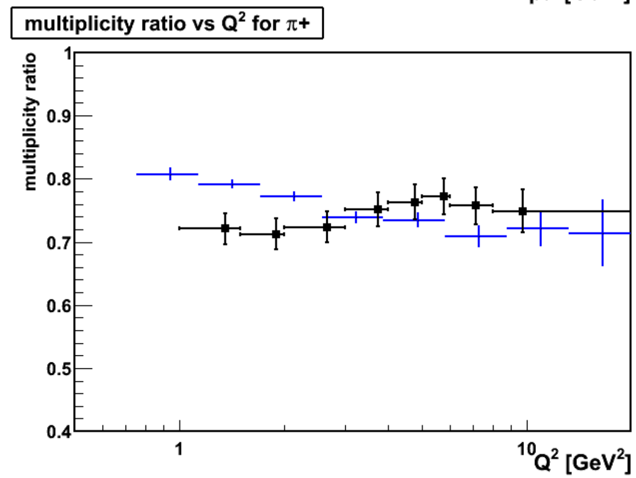
Energy loss effect under development

Comparison with Hermes data
27.6 GeV eXe vs eD

$$R_A^h(Q^2,\nu,z_h,P_\perp^2) = \frac{N_A^h(Q^2,\nu,z_h,P_\perp^2)/N_A^e(Q^2,\nu)}{N_D^h(Q^2,\nu,z_h,P_\perp^2)/N_D^e(Q^2,\nu)}$$







Summary & Prospects

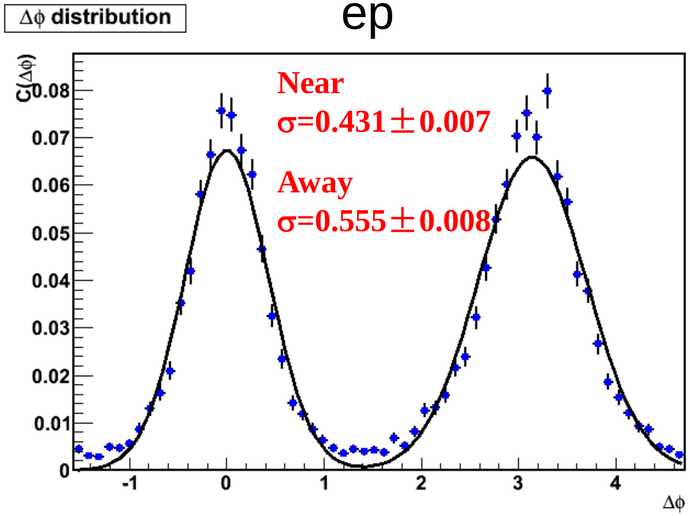
- Dihadron correlation is a very important measurement in the future eRHIC eA program.
- A generic Monte Carlo generator design based on pQCD calculation in the vacuum with flexible nuclear effects added on.
- Energy loss effect in cold nuclear medium to be included in this Monte Carlo.
- Can be utilized to understand dA or pA data and extract the model parameters as an input in our eAu simulation.

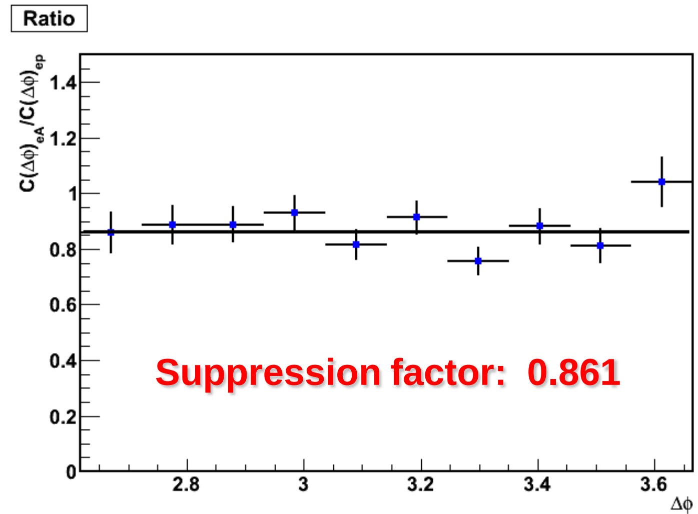
Thank you for your attention

Backup slides

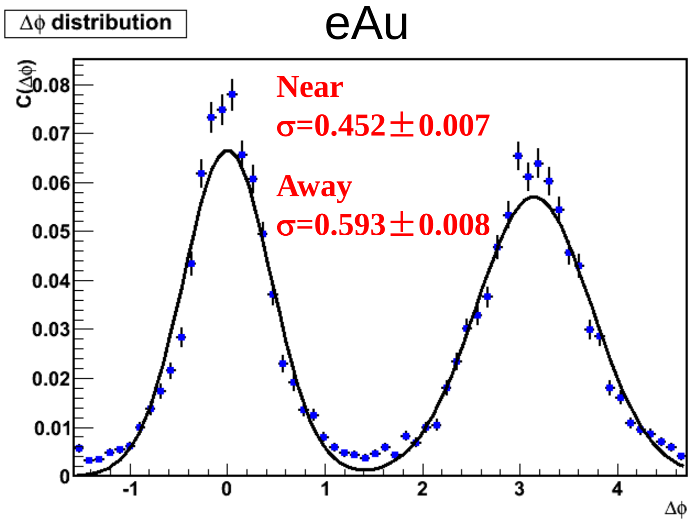
Results Q^2=1 GeV^2

ep





eAu



30+100GeV 10M events

Total cross section(ep):34.95nb

Integrated Luminosity(ep):0.286fb^{-1}

0.5<Q2<1.5, 0.6<y<0.8

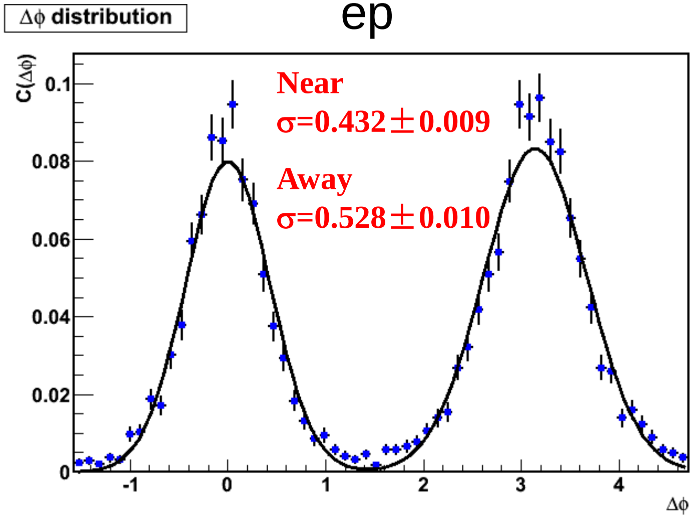
|η|<5 (0.772<θ<179.228),

p_t^{Trig}>2, 1<p_t^{Asso}<2

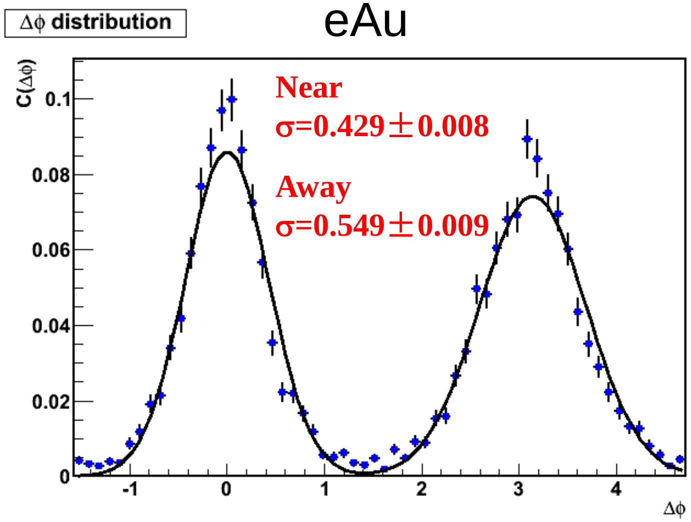
0.1<$z^{Trig,Asso}$<0.3

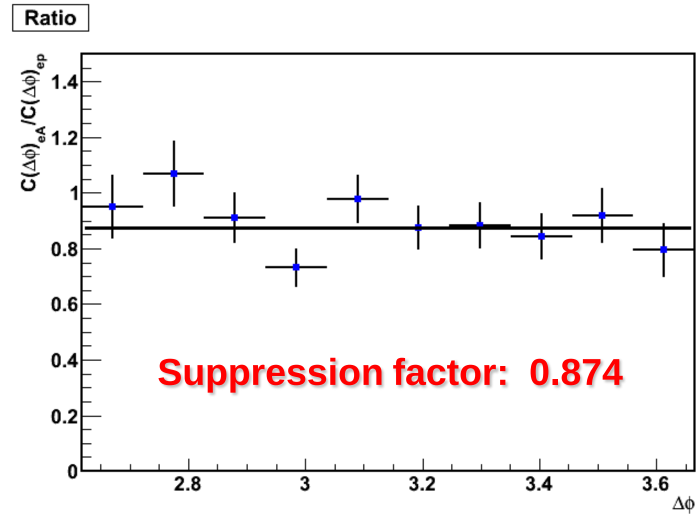
Results Q^2=4 GeV^2

ep



eAu





30+100GeV 2M events

Total cross section(ep):2.3nb

Integrated Luminosity(ep):0.87fb^{-1}

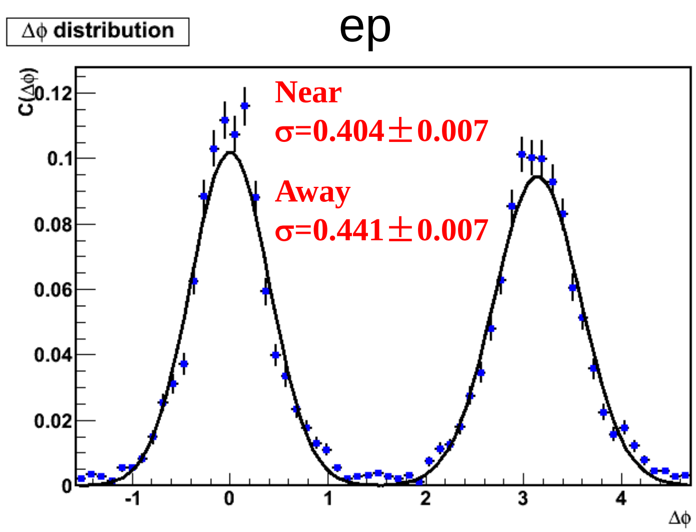
3.5<Q2<4.5, 0.6<y<0.8

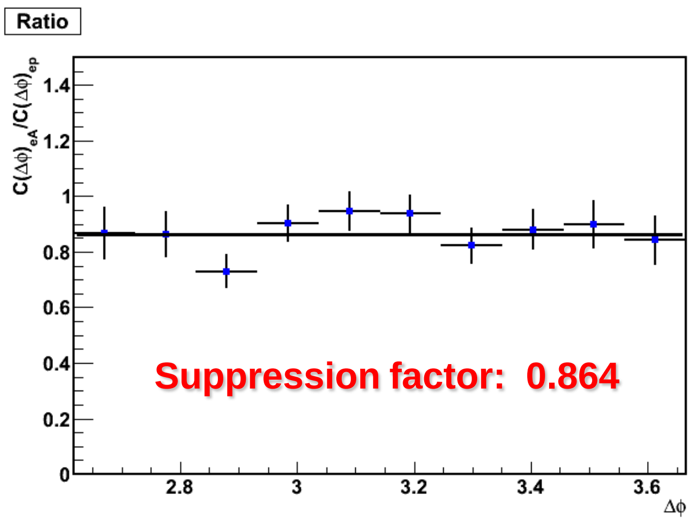
|η|<5 (0.772<θ<179.228),

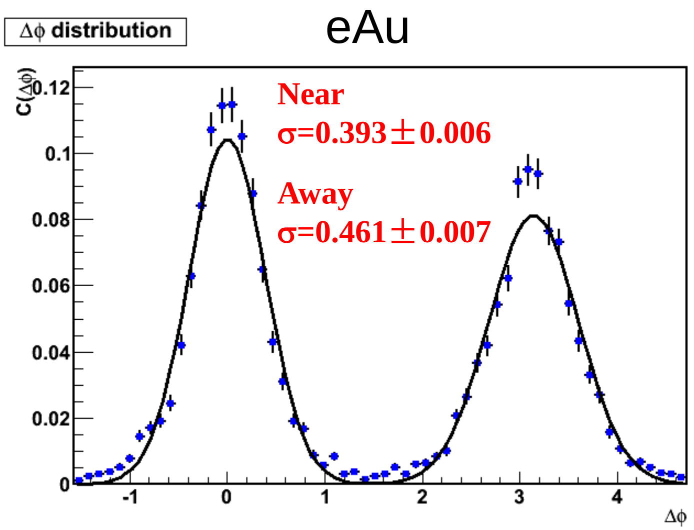
p_t^{Trig}>2, 1<p_t^{Asso}<2

0.1<z ^{Trig,Asso}<0.3

Results Q^2=10 GeV^2







30+100GeV 2M events

Total cross section(ep):0.414nb

Integrated Luminosity(ep):4.83fb^{-1}

9.5<Q2<10.5, 0.6<y<0.8

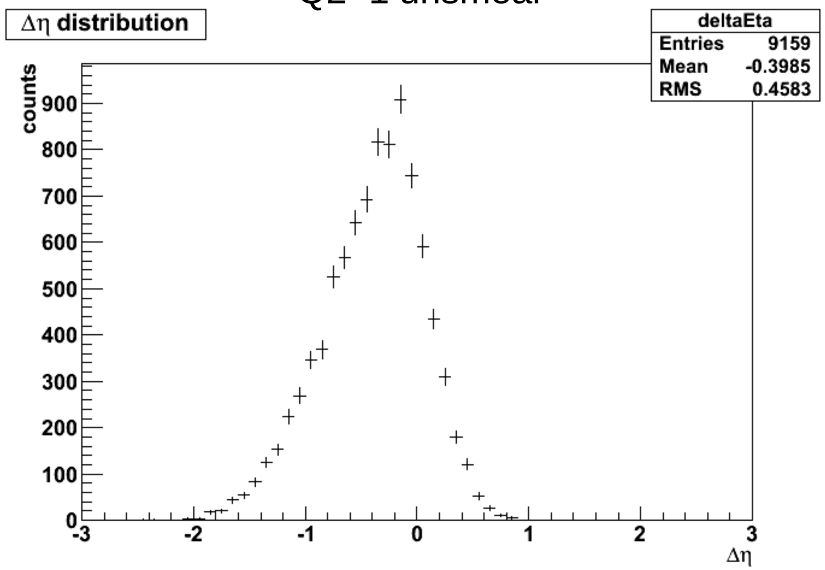
|η|<5 (0.772<θ<179.228),

p_t^{Trig}>2, 1<p_t^{Asso}<2

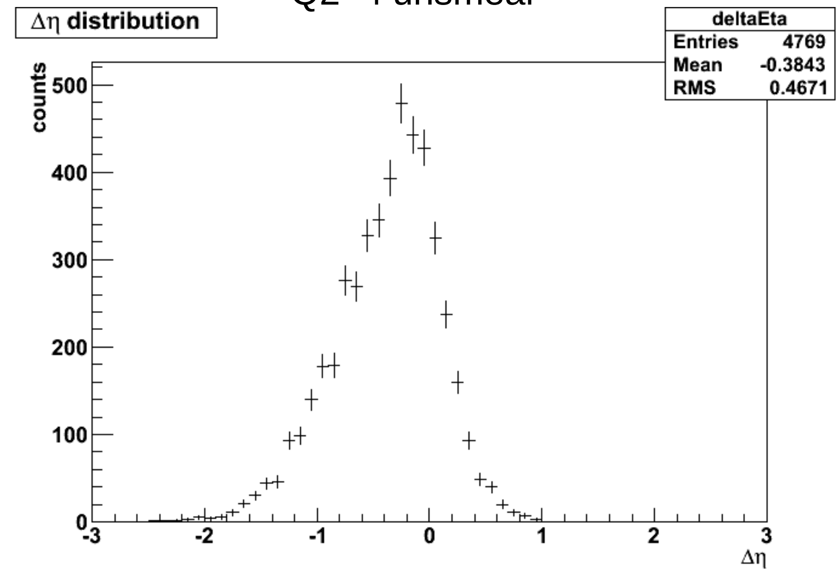
0.1<$z^{Trig,Asso}$<0.3

	ep			eAu			eA/ep
	Trig frac Total/accpt	σ(Near)	σ(Away)	Trig frac Total/accpt	σ(Near)	σ(Away)	ratio
Q2=1	0.538%	0.431±0.007	0.555±0.008	0.706%	0.452±0.007	0.593±0.008	0.861±0.043
Q2=4	1.176%	0.432±0.009	0.528±0.010	1.503%	0.429±0.008	0.549±0.009	0.874±0.026
Q2=10	1.619%	0.404±0.007	0.441±0.007	1.958%	0.393±0.006	0.461±0.007	0.864±0.024

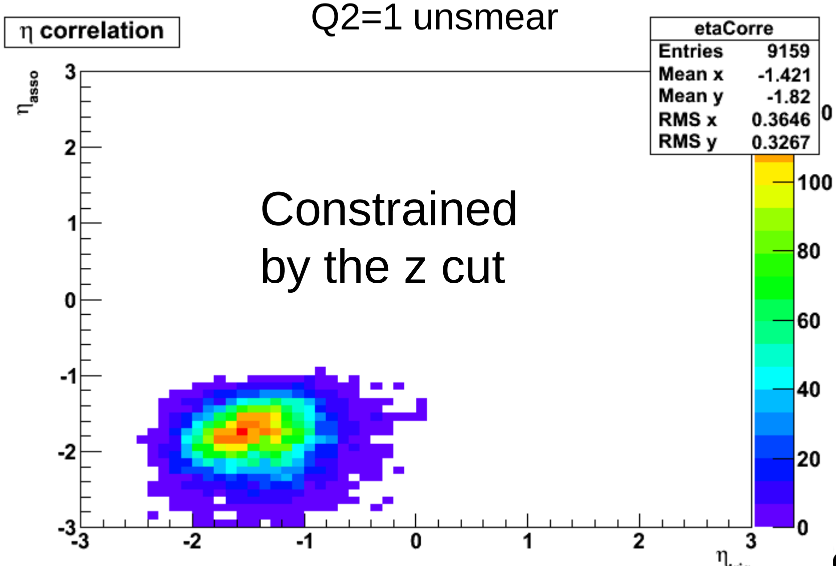
Q2=1 unsmear



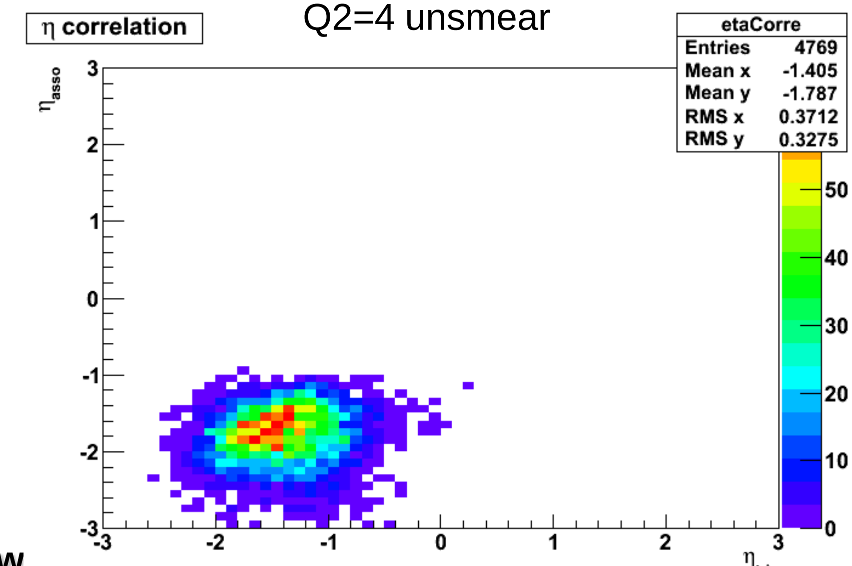
Q2=4 unsmear



Q2=1 unsmear



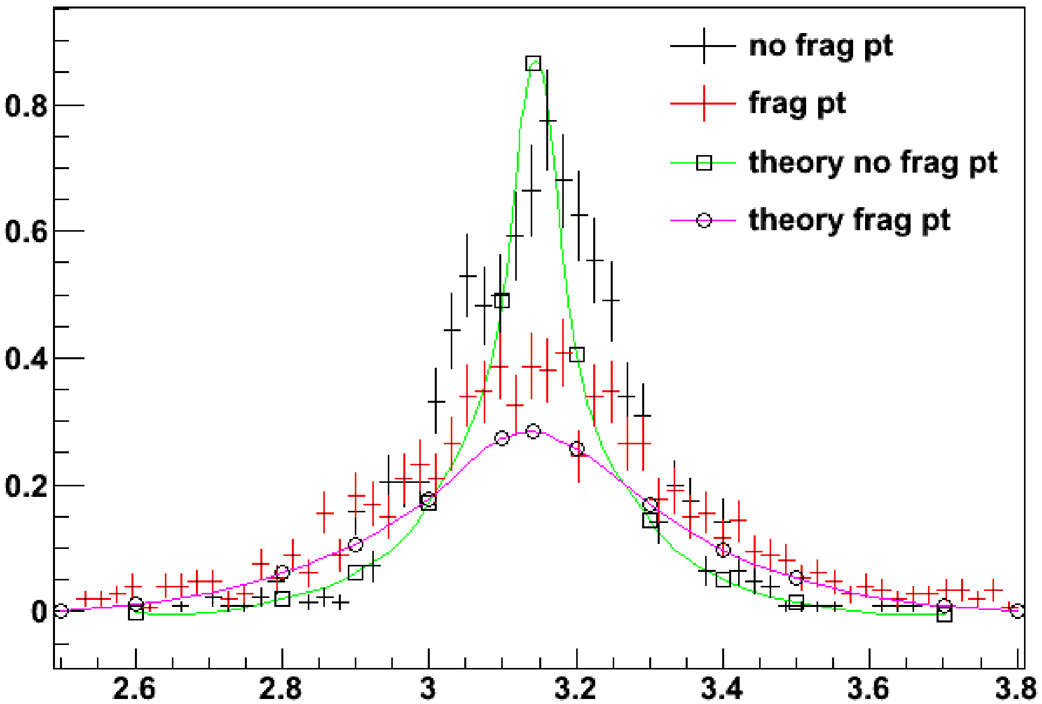
Q2=4 unsmear



MC cuts:

Pi0 3.5<Q2<4.5 0.65<y<0.75

Pt trig>2GeV 1GeV<Pt asso<Pt trig0.25<z1,z2<0.35



Parton shower must be switched off and a reasonable intrinsic kt is necessary for this reproduction of ep correlation function.

e+p/A(30+100)

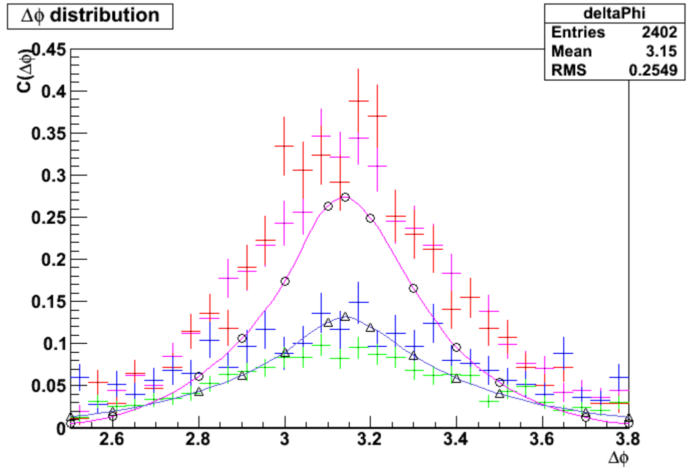
MC cuts:

pi0

3.5<Q2<4.5,0.65<y<0.75

pt1>2GeV,1GeV<pt2<pt1

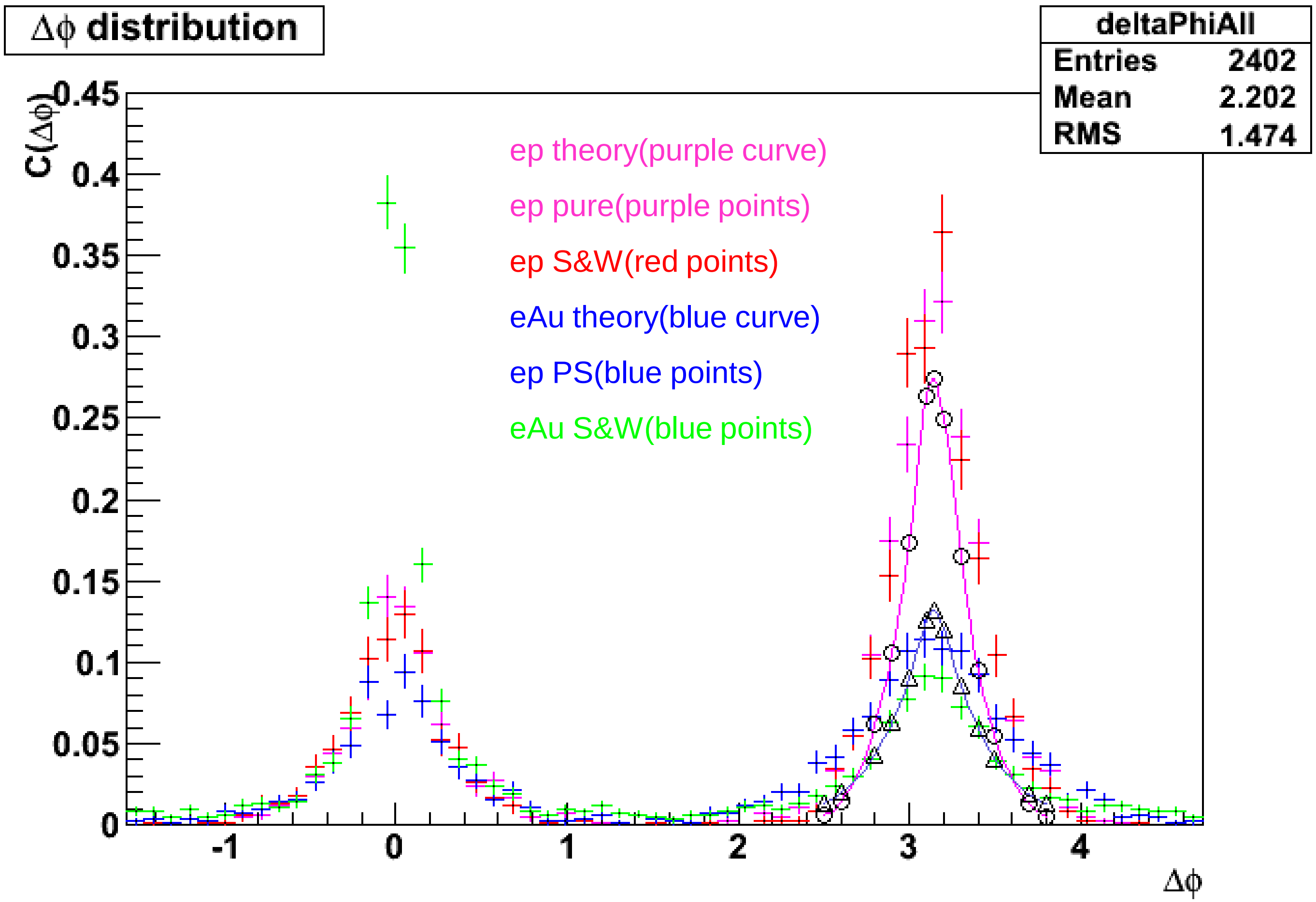
0.25<z<0.35



eAu(S&W)/ep(S&W)=0.27

eAu(S&W)/ep(PS)=0.76

eAu(theory)/ep(theory)=0.48



Q2=1

Process fraction in current Bin:

LODIS:52.7%   PGF:5%   QCDC:1.66%

DIFF:12.8% Resovled:21.26%

Contribution to dihadron:

PGF:54.45%   QCDC:7.75%
Resovled:37.42%

Q2=4

Process fraction in current Bin:

LODIS:67.44%   PGF:7.43%   QCDC:2.06%

DIFF:8.35% Resovled:10.61%

Contribution to dihadron:

PGF:66.22%   QCDC:11.09%
Resovled:22.42%

Q2=10

Process fraction in current Bin:

LODIS:80.87%   PGF:4.88%   QCDC:1.54%

DIFF:4.98% Resovled:5.43%

Contribution to dihadron:

PGF:68.63%   QCDC:15.18%
Resovled:13.08%

The power of Monte Carlo

Jetset fragmentation

MC cuts:

3.5<Q2<4.5

0.65<y<0.75

pt trig>2GeV

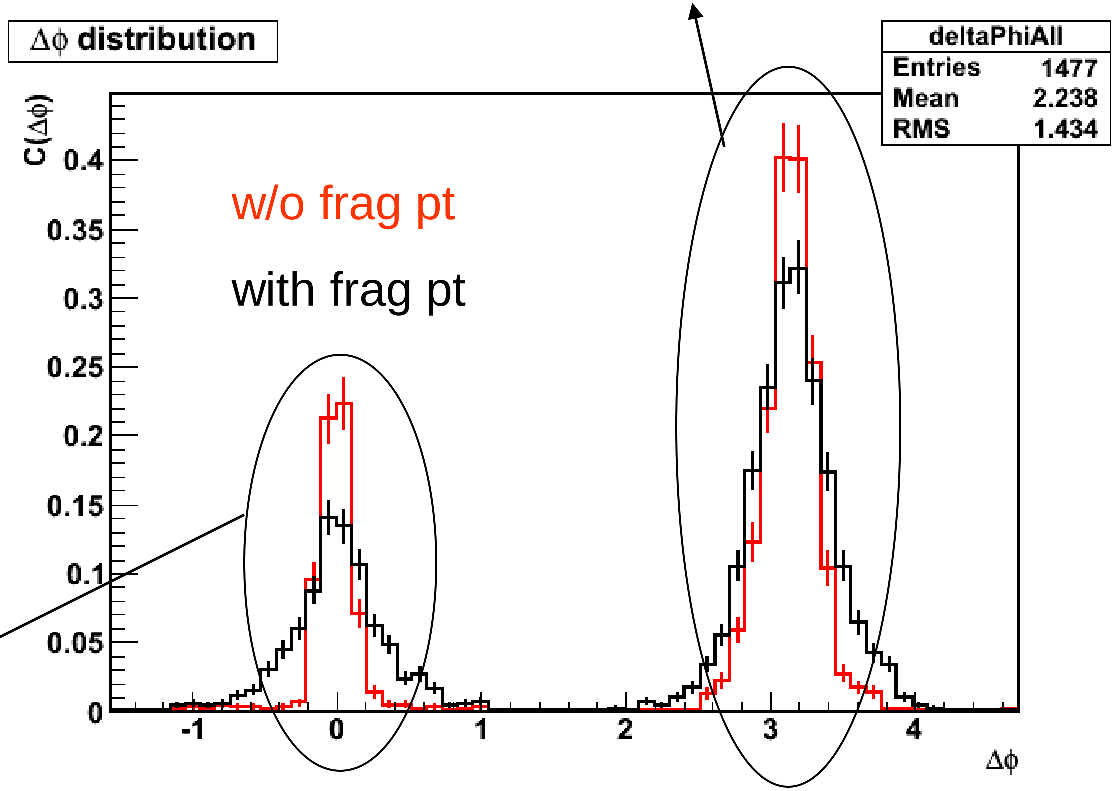
1<pt asso<pt trig

0.25<z1,z2<0.35

Intrinsic kt =0.7

Fragmentation pt=0.4

Away side dominated by the intrinsic kt

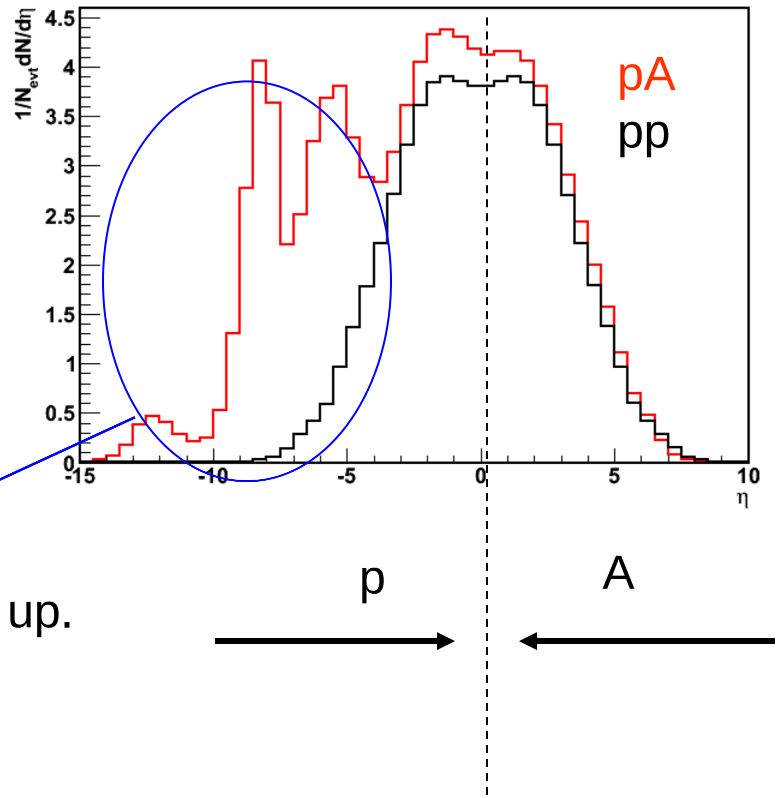


Near side mostly affected by the fragmentation pt.

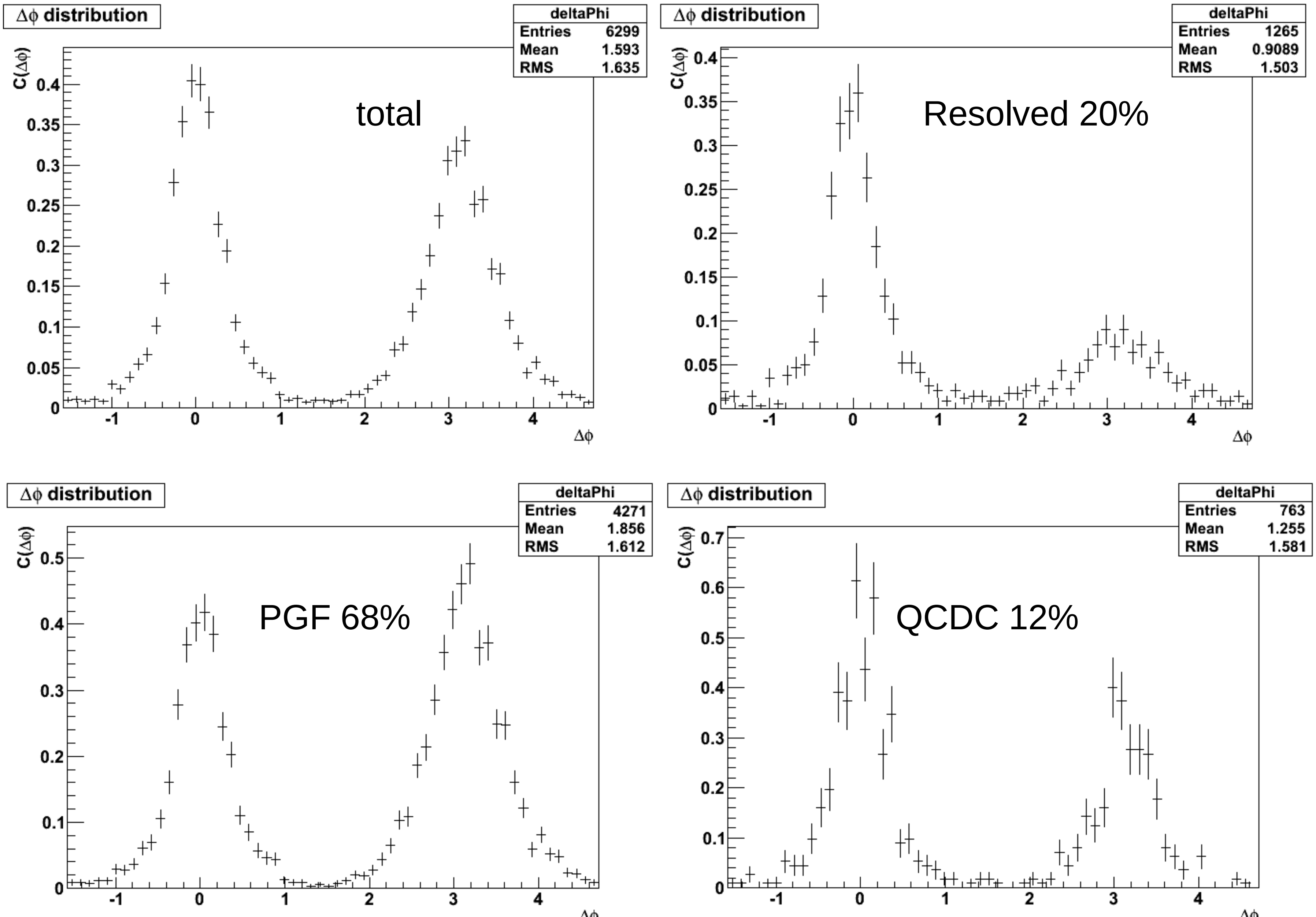
Possible application in pA

Extending to the pA collision.
Replace the PDF in PYTHIA for the nucleus beam, nuclear break up add on.

pA Ncoll=1 compared to pp

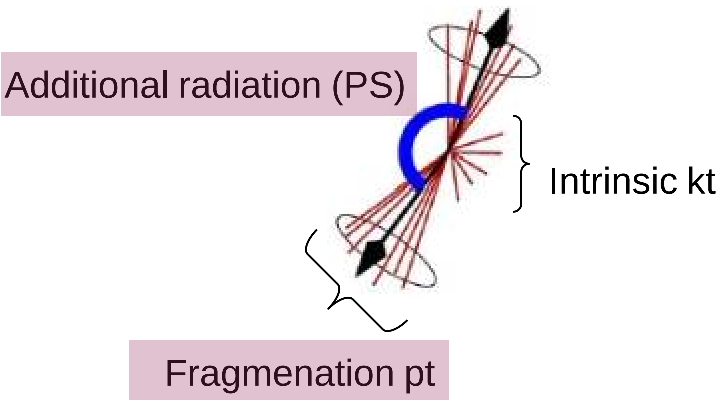


Nucleus remnant region,
Structure from nuclear break up.

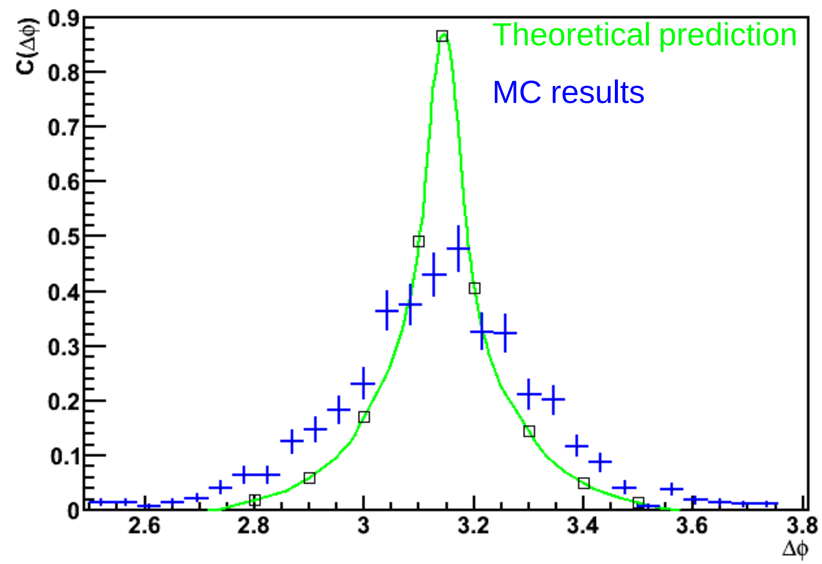

Δφ distribution
deltaPhi
Entries 6299
Mean 1.593
RMS 1.635
total
C(Δφ)
Δφ
Δφ distribution
deltaPhi
Entries 1265
Mean 0.9089
RMS 1.503
Resolved 20%
C(Δφ)
Δφ
Δφ distribution
deltaPhi
Entries 4271
Mean 1.856
RMS 1.612
PGF 68%
C(Δφ)
Δφ
Δφ distribution
deltaPhi
Entries 763
Mean 1.255
RMS 1.581
QCDC 12%
C(Δφ)
Δφ

The power of Monte Carlo

3 factors matter a lot in the decorrelation of back to back jets.



Intrinsic k_t=0.7GeV ~ $0.4<Qs^2<0.6$ GeV^2 in the model
No fragmentation pt.



Theoretical curves from B.W.Xiao

MC cuts:

$3.5<Q^2<4.5$

$0.65<y<0.75$

pt trig>2GeV

1<pt asso<pt trig

0.25<z1,z2<0.35

PARP(91)=0.7

PARJ(21)=0.

Theoretical cuts:

$Q^2=4$

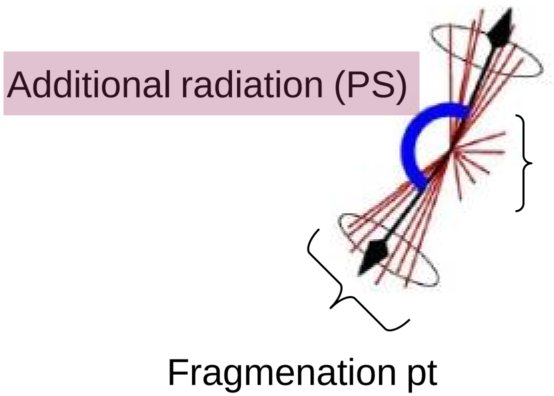
y=0.7

pt trig>2GeV

1<pt asso<pt trig

z1=z2=0.3

The power of Monte Carlo



3 factors matter a lot in the decorrelation of back to back jets.

Intrinsic k_t=0.7GeV ~ 0.4<Qs^2<0.6 GeV^2 in the model
Fragmentation pt=0.4GeV ~ <pt^2>=0.2GeV^2 in the model

MC cuts:

3.5<Q^2<4.5

0.65<y<0.75

pt trig>2GeV

1<pt asso<pt trig

0.25<z1,z2<0.35

PARP(91)=0.7

PARJ(21)=0.4

Theoretical cuts:

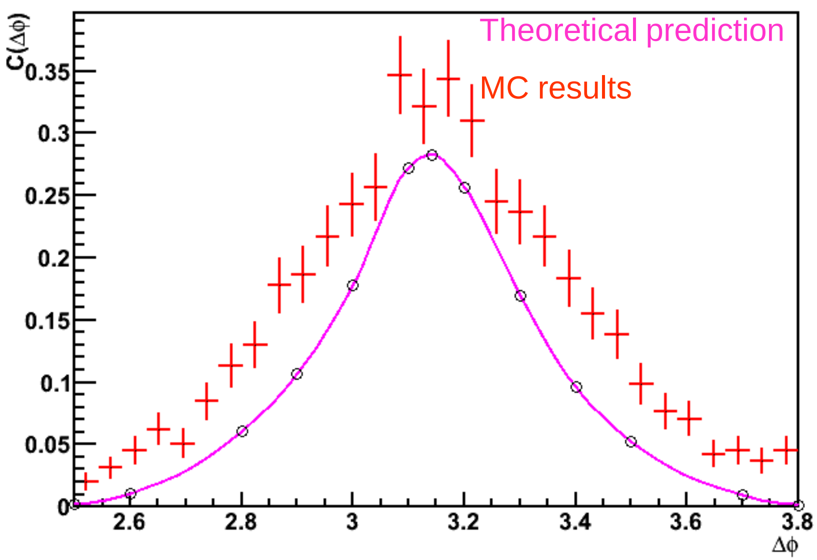
Q^2=4

y=0.7

pt trig>2GeV

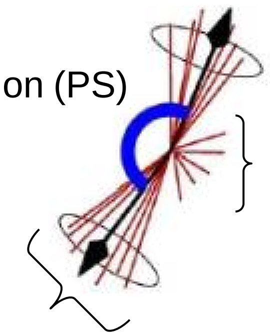
1<pt asso<pt trig

z1=z2=0.3



Theoretical curves from B.W.Xiao

The power of Monte Carlo



3 factors matter a lot in the decorrelation of back to back jets.

MC cuts:

$3.5<Q^2<4.5$

$0.65<y<0.75$

pt trig>2GeV

1<pt asso<pt trig

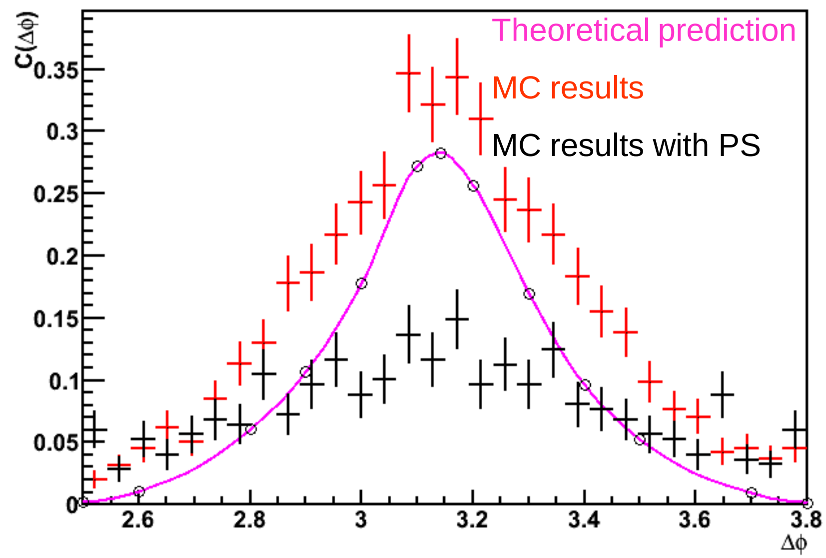
0.25<z1,z2<0.35

PARP(91)=0.7

PARJ(21)=0.4

Add PS effect to the theoretical curve

Intrinsic k_t=0.7GeV ~ $0.4<Qs^2<0.6$ GeV^2 in the model
Fragmentation pt=0.4GeV ~ $<pt^2>=0.2GeV^2$ in the model



Theoretical curves from B.W.Xiao